



Fermi National Accelerator Laboratory

FERMILAB-TM-1875

Summary of the Radiation Damage Studies of the SDC Dopants in Polystyrene

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Studies of the SDC
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Introduction

Approximately 80 commercially available fluorescent organic compounds were studied as dopants in a polystyrene matrix for possible use in wavelength shifting (WLS) fibers. The goal was to find a new green-emitting WLS fiber which would outperform in light yield and decay time the currently available fiber doped with K-27. Therefore the fluorescent compounds of interest should exhibit the following spectroscopic characteristics in polystyrene: $\lambda_{abs}=400\text{--}450$ nm, $\lambda_{em}=450\text{--}550$ nm, $\tau=3\text{--}7$ ns ($\tau=12$ ns for K-27), and quantum efficiency of minimum 0.7 (K-27 baseline). For further details on the range and properties of the compounds studied refer to "Final Results from the SDC Dopant Search for New Green Wavelength Shifting (WLS) Fibers", FERMILAB-TM-1873.

Polystyrene samples doped with different fluorescent compounds were prepared and characterized. Of all the compounds tested, only a series of coumarins exhibited the spectroscopic characteristics of interest. Radiation damage studies had to be performed on these samples in order to conclusively determine if they were better candidates than K-27 for green WLS fibers.

All samples except those showing opacity or deep coloration were irradiated. They were, however, separated in two sets. Radiation damage set No. 20 (RD20) was mainly formed by the coumarin derivatives. Radiation damage set No. 22 (RD22) was based on the remaining samples. The irradiations were performed at the Phoenix Memorial Laboratory (University of Michigan) using a ^{60}Co source. Both sets were exposed to a total dose of 10 Mrad in air, at a dose rate of 1.8 Mrad/h. Transmittance measurements were recorded before and after irradiation, and after annealing. After irradiation, the samples were annealed in oxygen to accelerate the recovery process. Although the samples were irradiated in air, they still underwent annealing in oxygen atmosphere because the dose rate had been high enough for the oxygen diffusion rate to be smaller than its consumption rate during irradiation. The final results are similar to those of an irradiation under inert atmosphere, with the exception of the formation of oxidation products on the surface of the samples.

Transmittance spectra were recorded with a Hewlett-Packard model 8451A diode array spectrophotometer. All transmittance measurements used undoped and unirradiated polystyrene as the reference. The transmittance

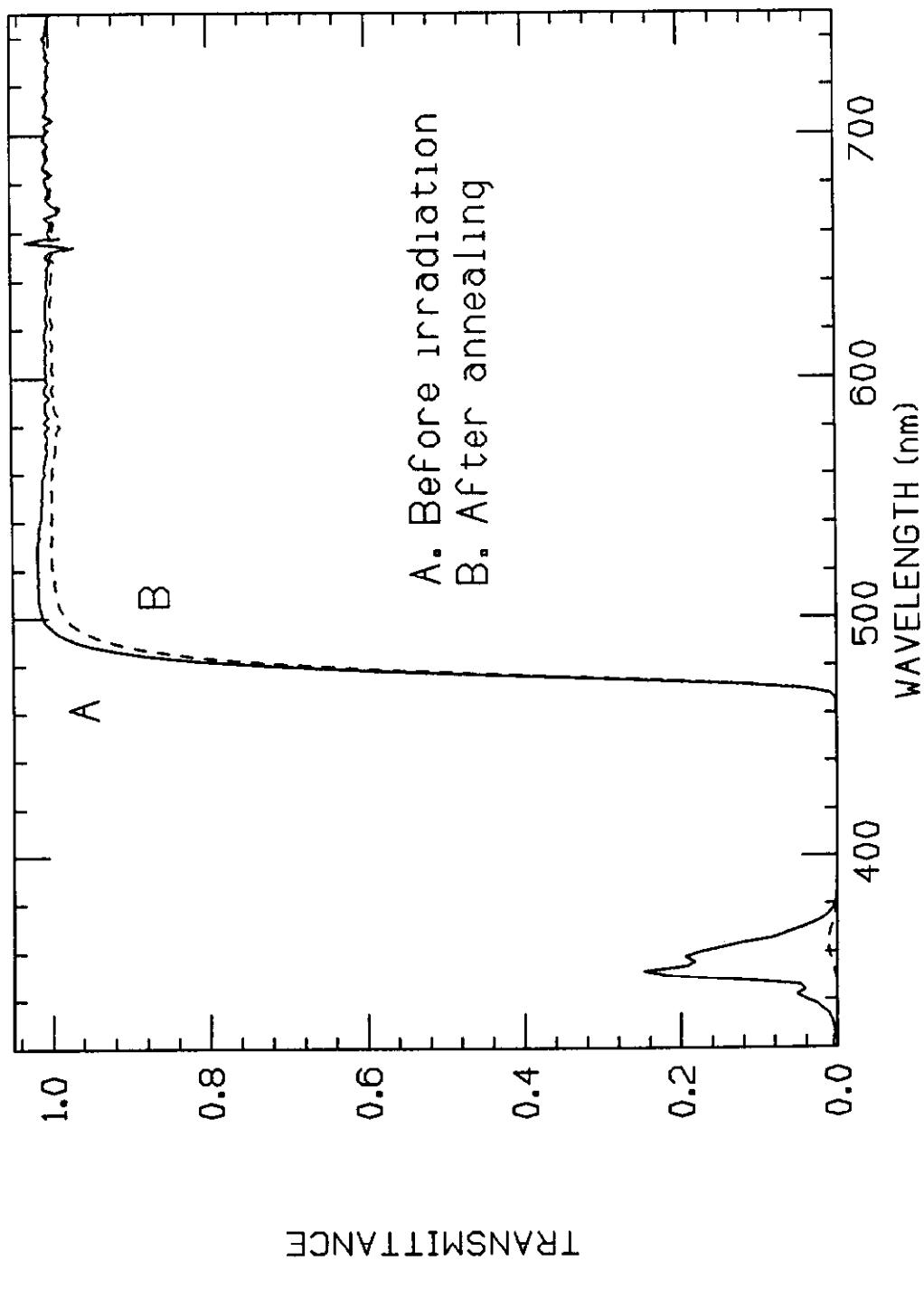
plots presented here observe the formal separation of the two sets, RD20 and RD22. The data for RD20 has been arranged in two plots for each dopant. The first plot shows the transmittance spectra before irradiation and after annealing. The second plot includes the transmittance spectra before irradiation plus two transmittance spectra recorded while the sample was annealing. For RD22, the data is shown in one single plot containing three measurements: one before irradiation, one after irradiation, and one after annealing in oxygen.

The RD20 data indicates that the performance under irradiation of the coumarins is significantly inferior to that of K-27. The losses in transmission of the coumarins are larger than those of K-27.

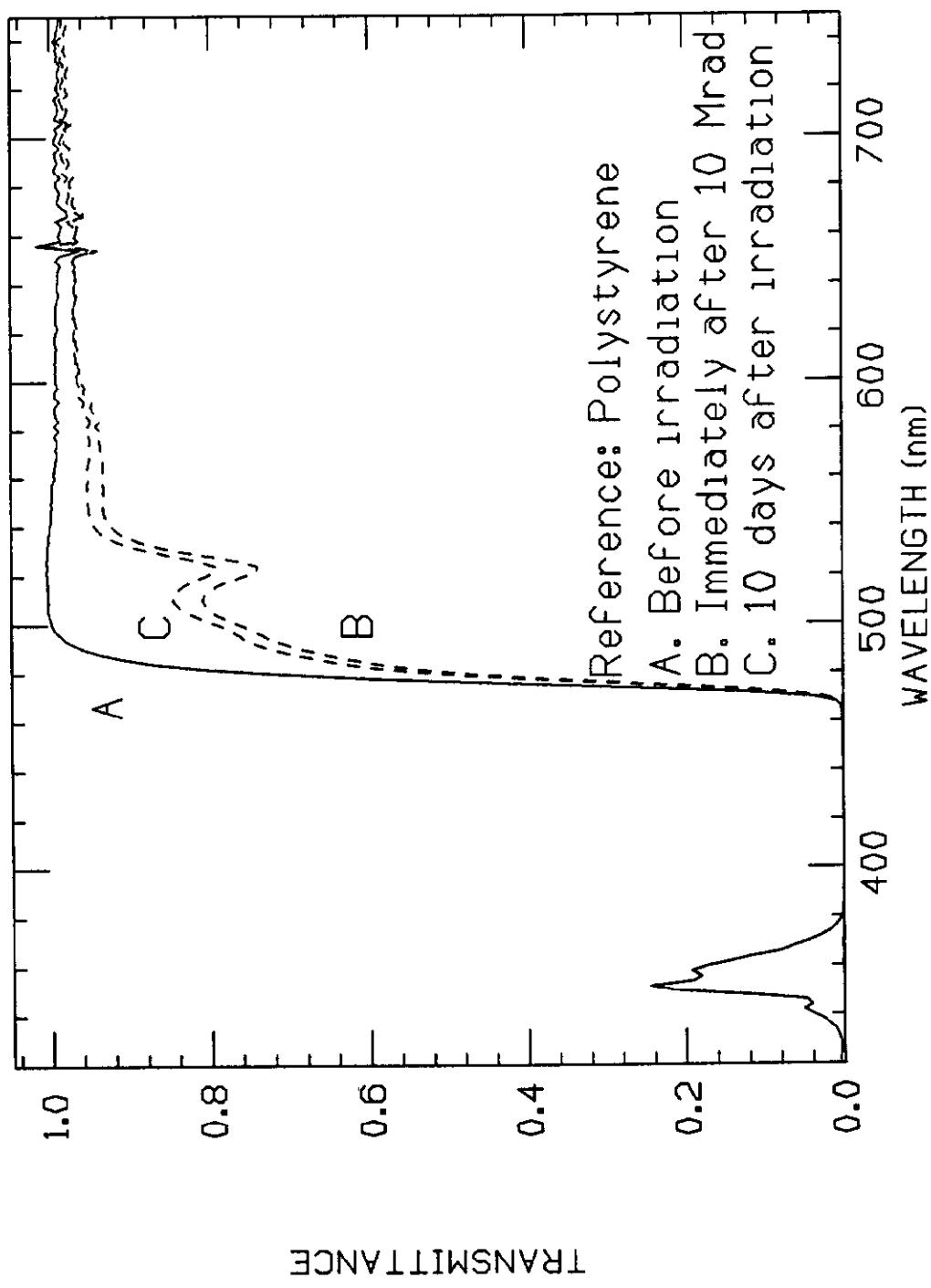
We wish to thank R. Blackburn of the Phoenix Memorial Laboratory of the University of Michigan for performing all sample irradiations. We wish to extend our appreciation to the members of the Particle Detector Group; in particular, Monica Szelag who plotted and organized the data presented in this document.

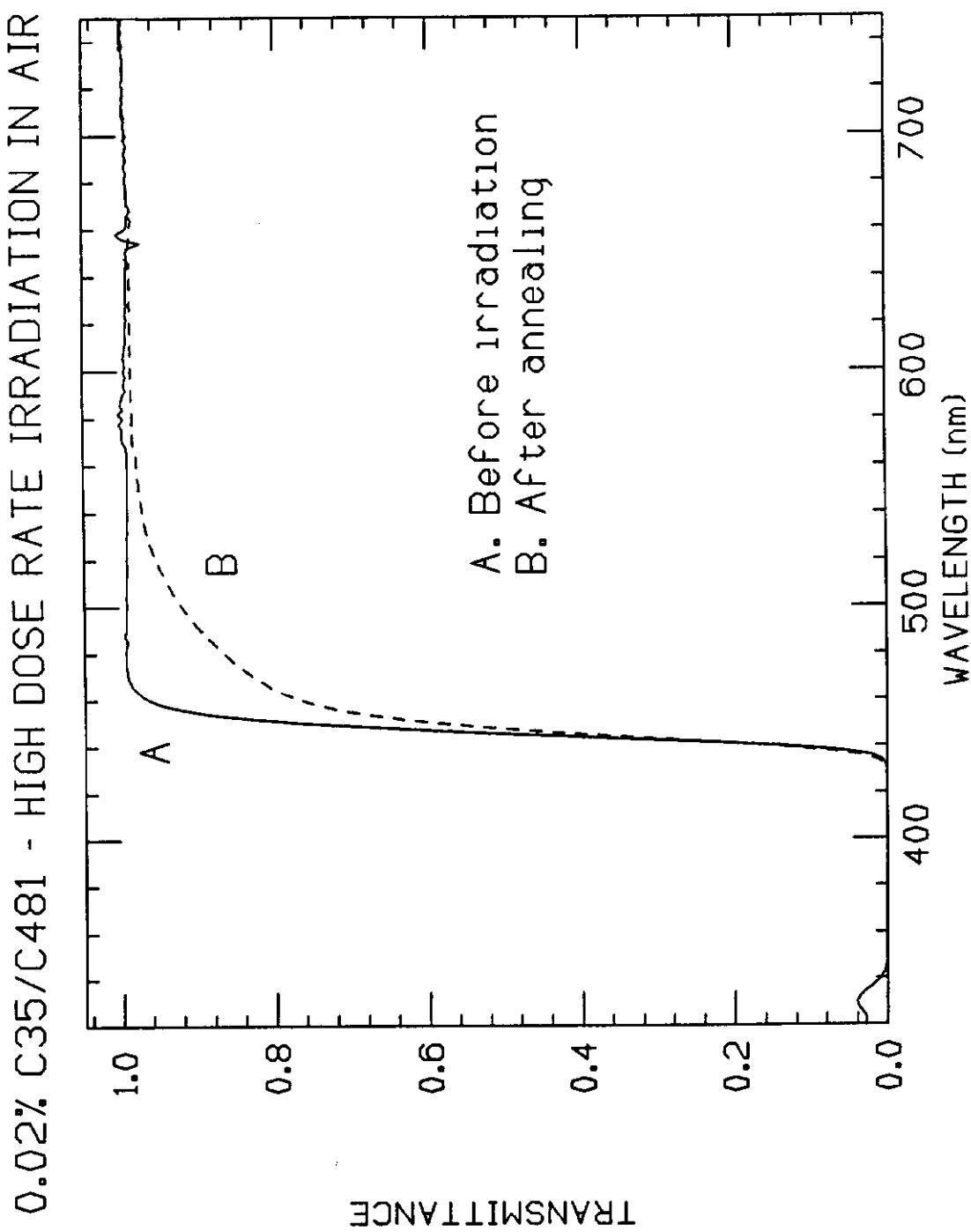
PART I
RADIATION DAMAGE SET #20

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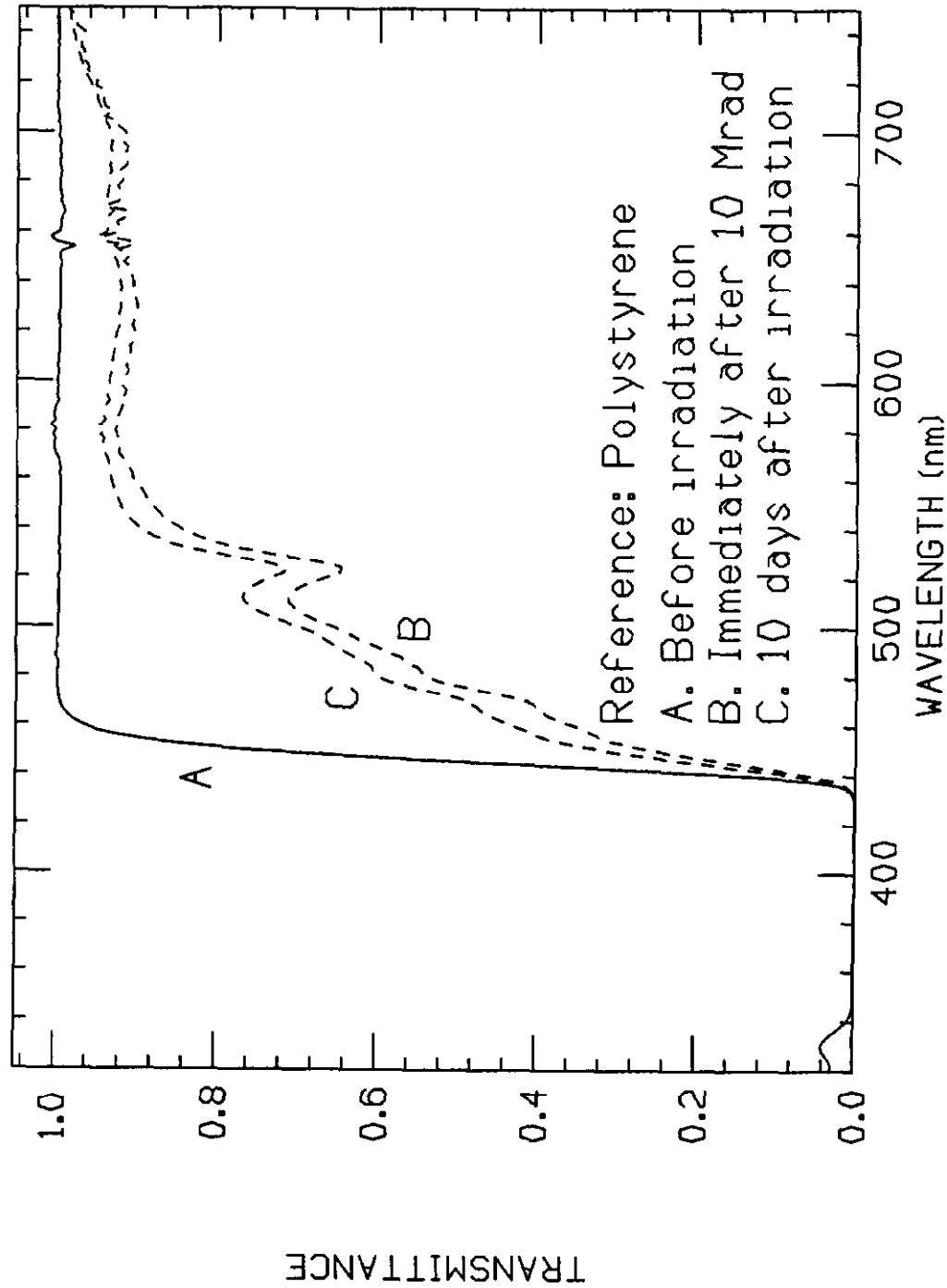


0.02% K27 - HIGH DOSE RATE IRRADIATION IN AIR

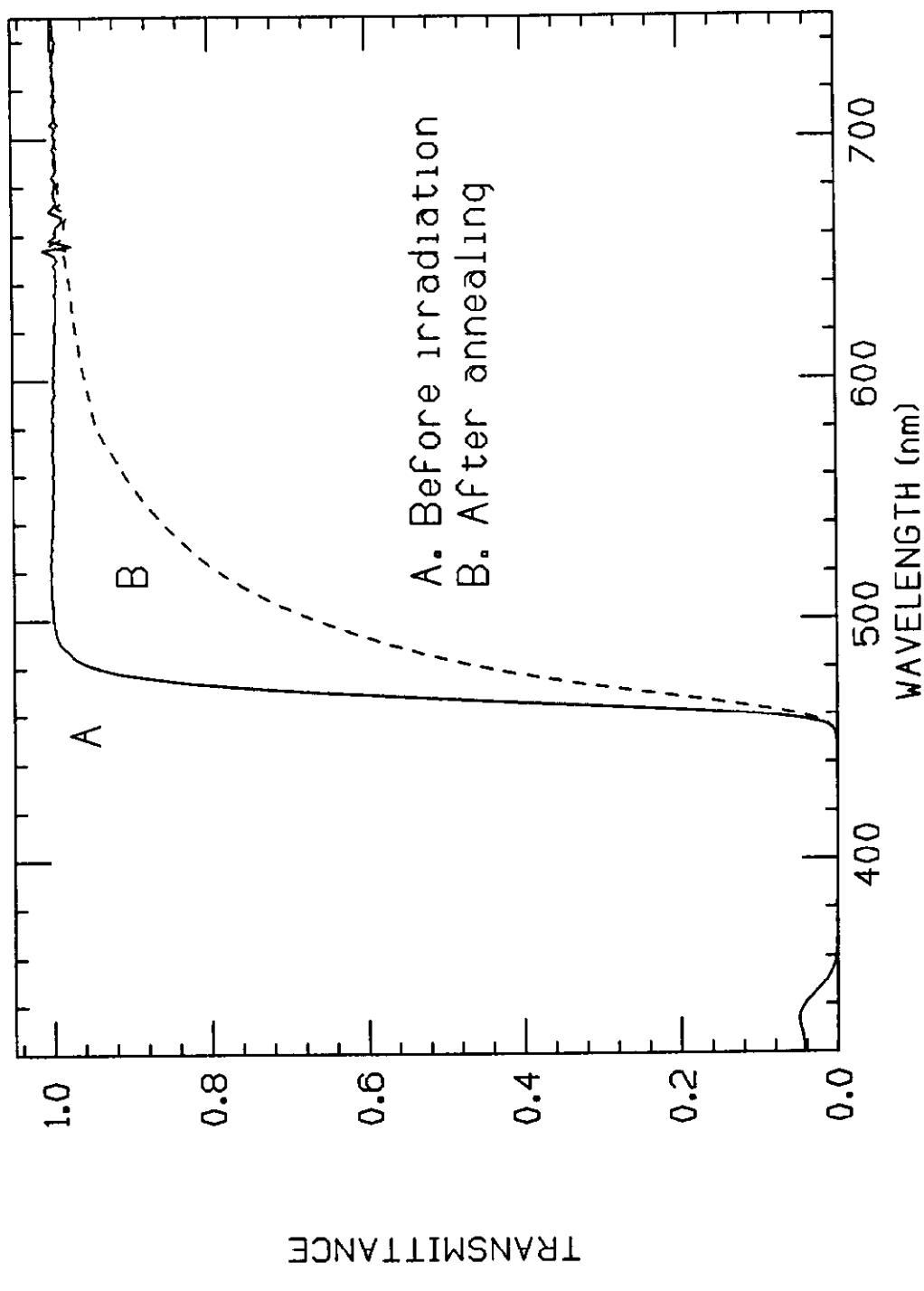




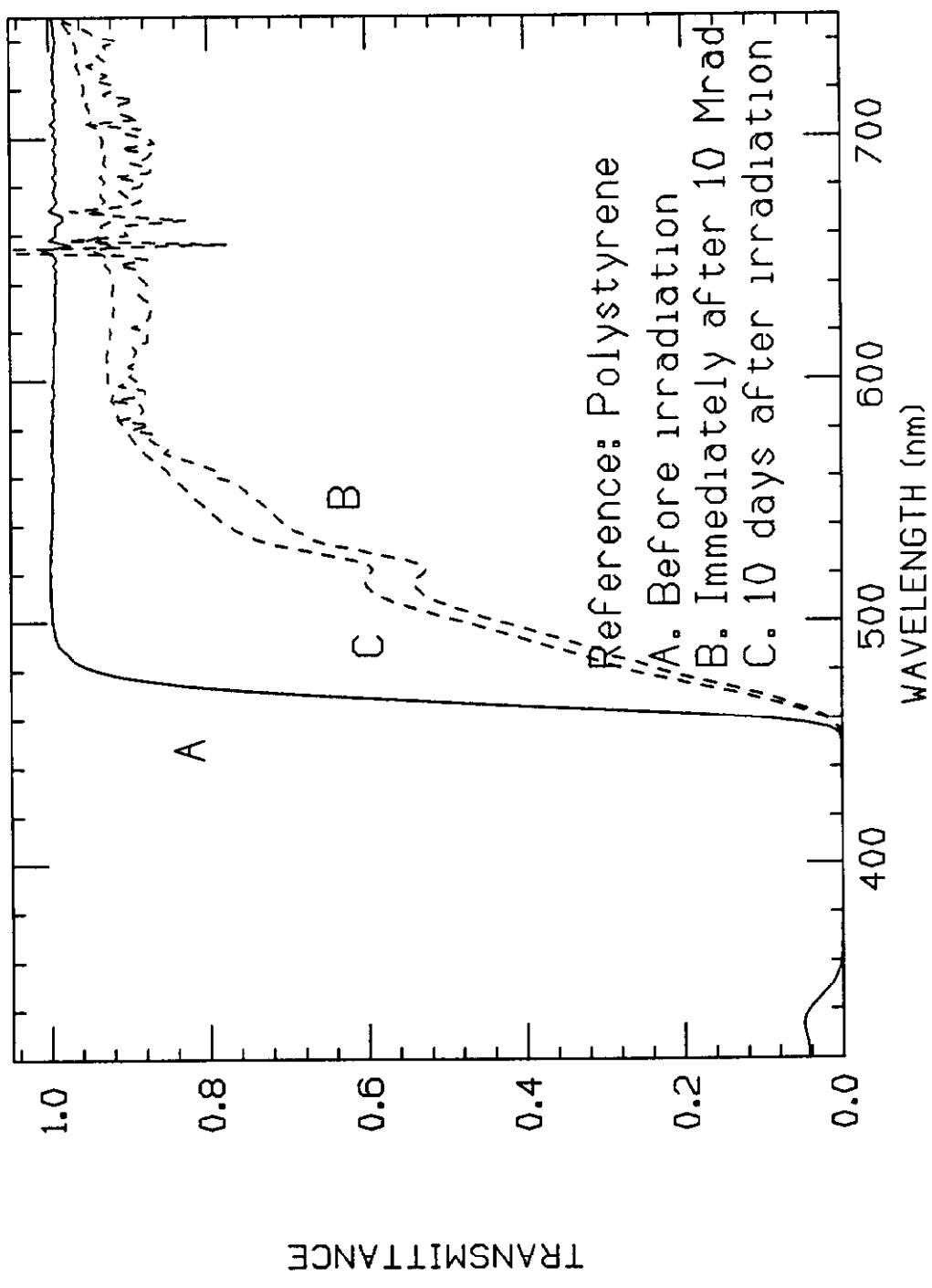
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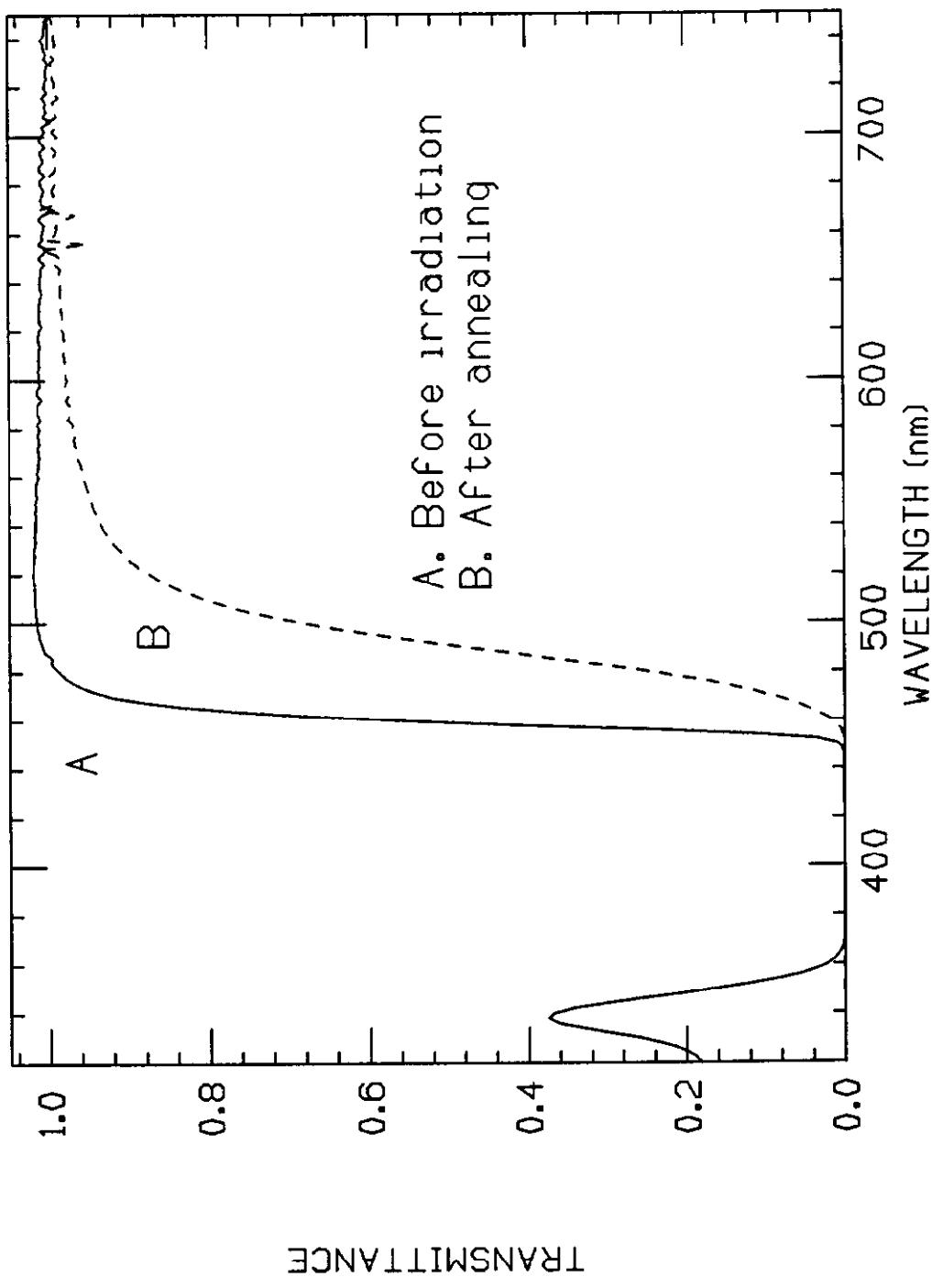
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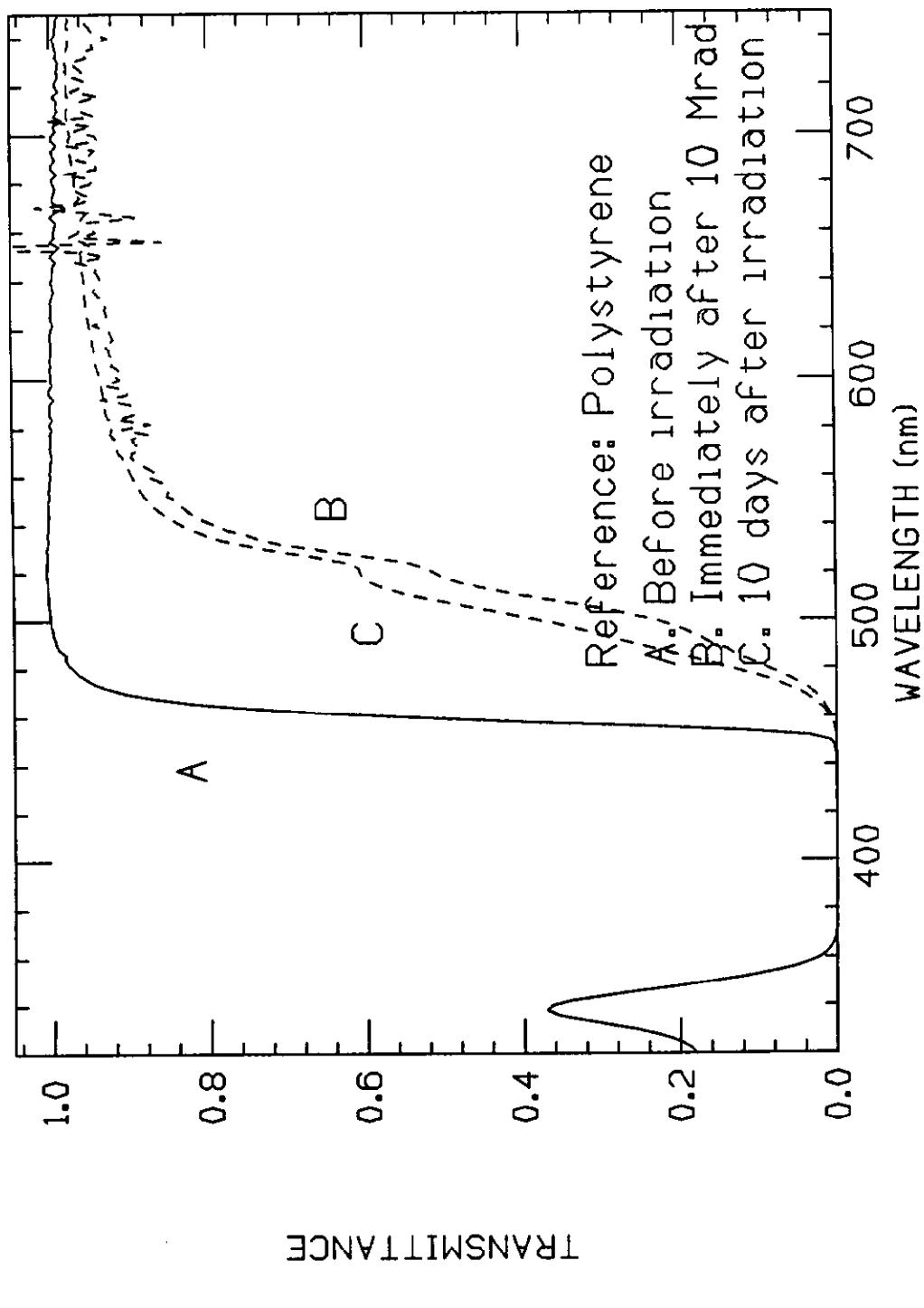
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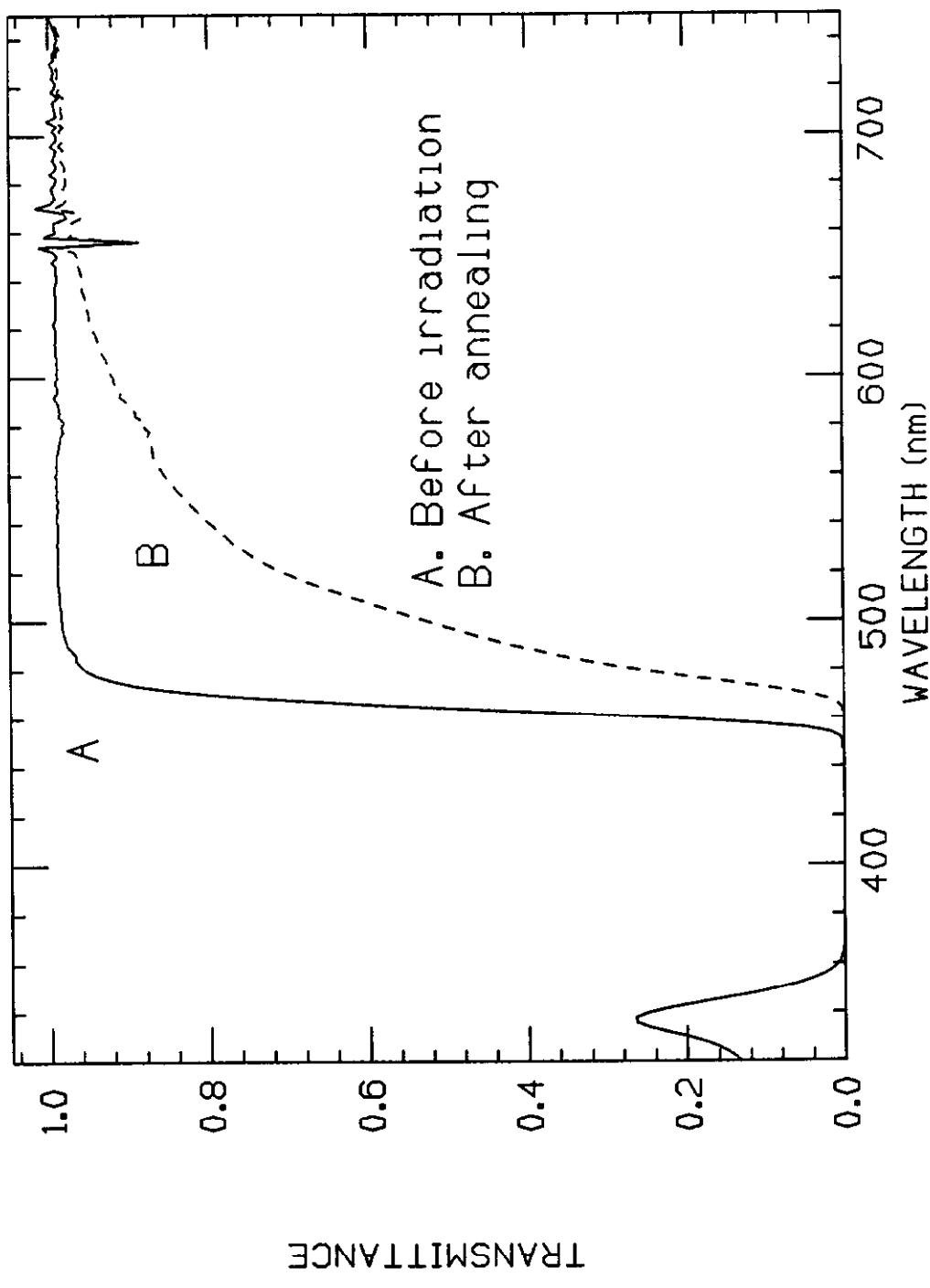
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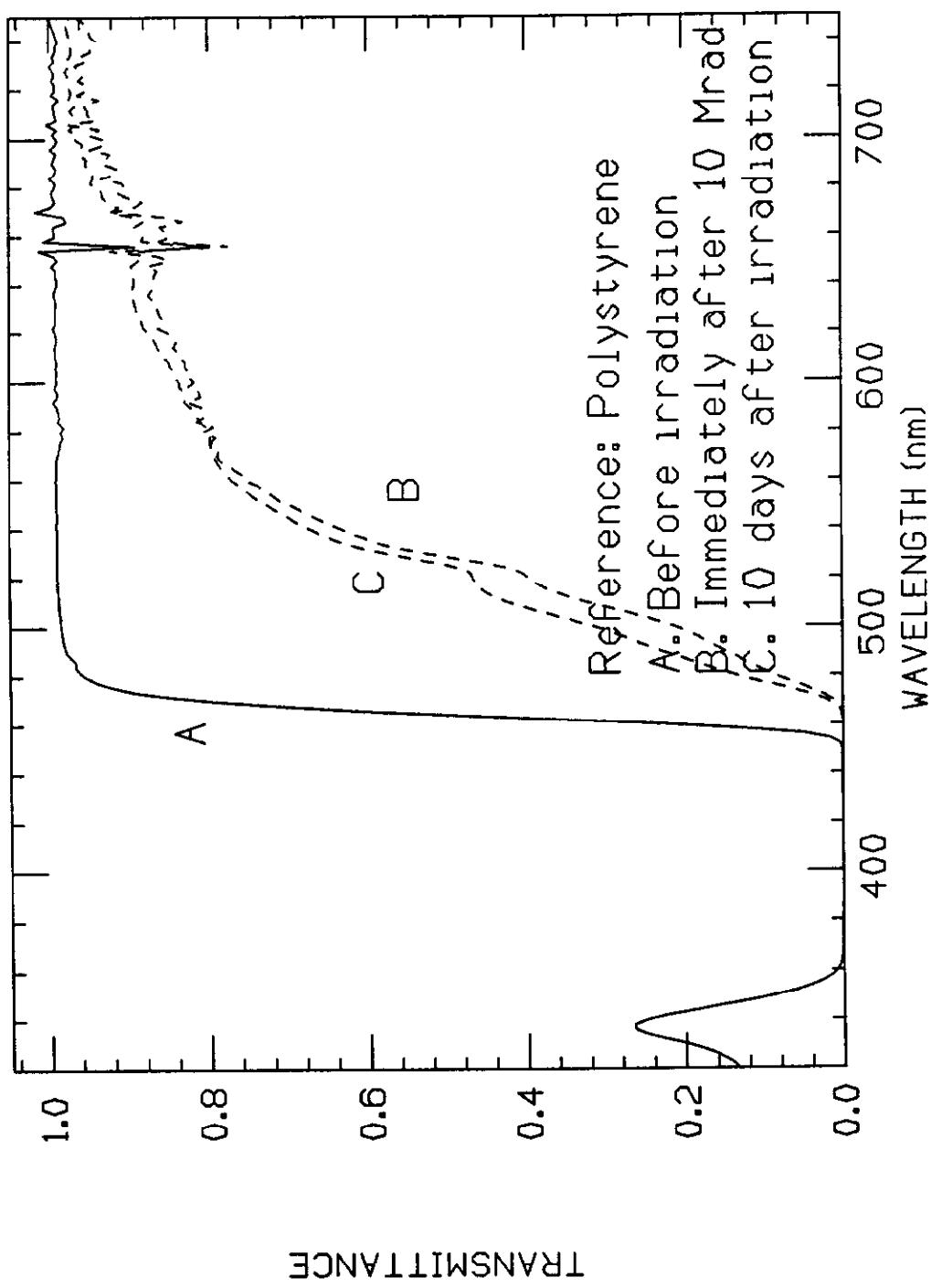
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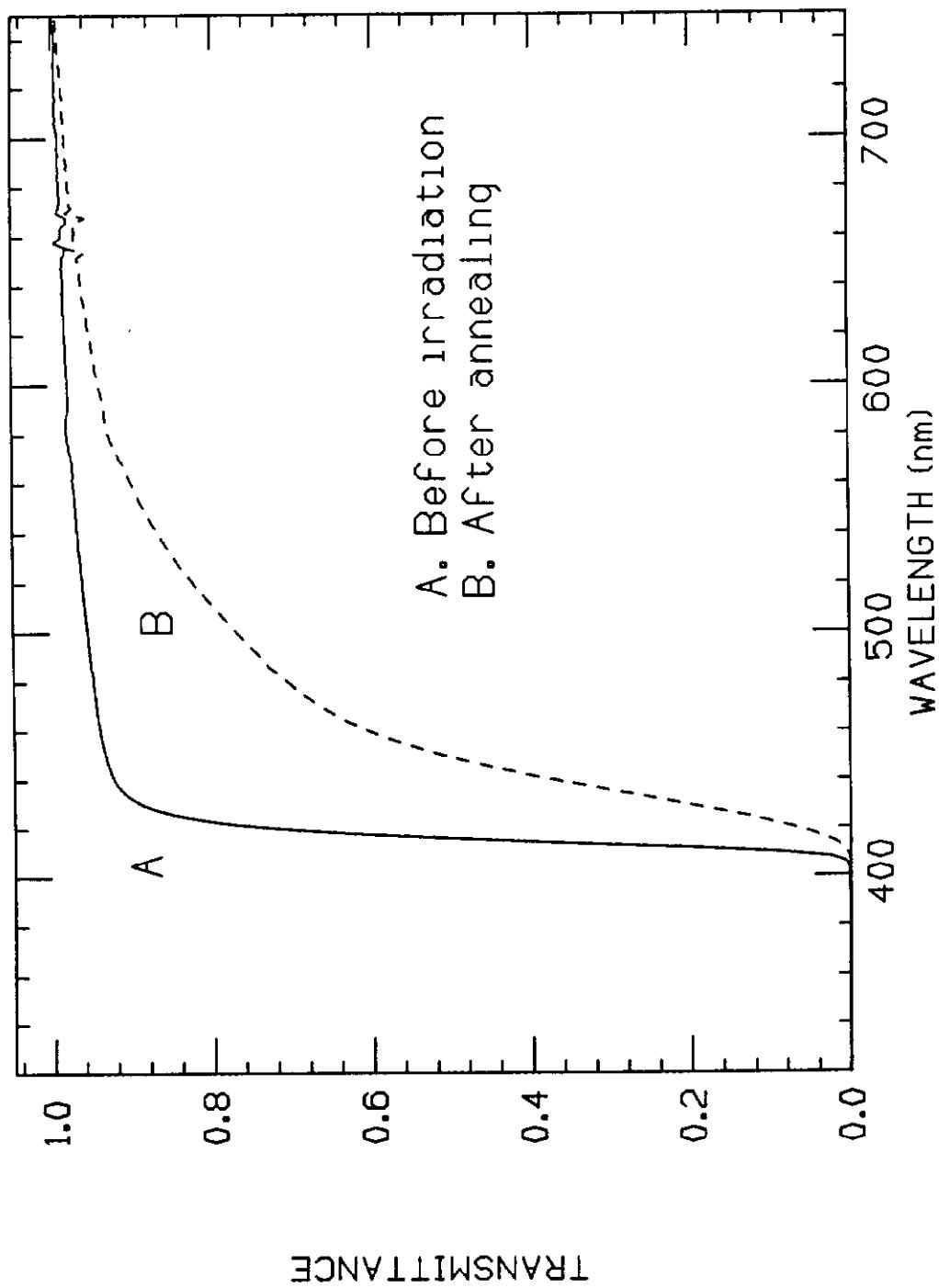
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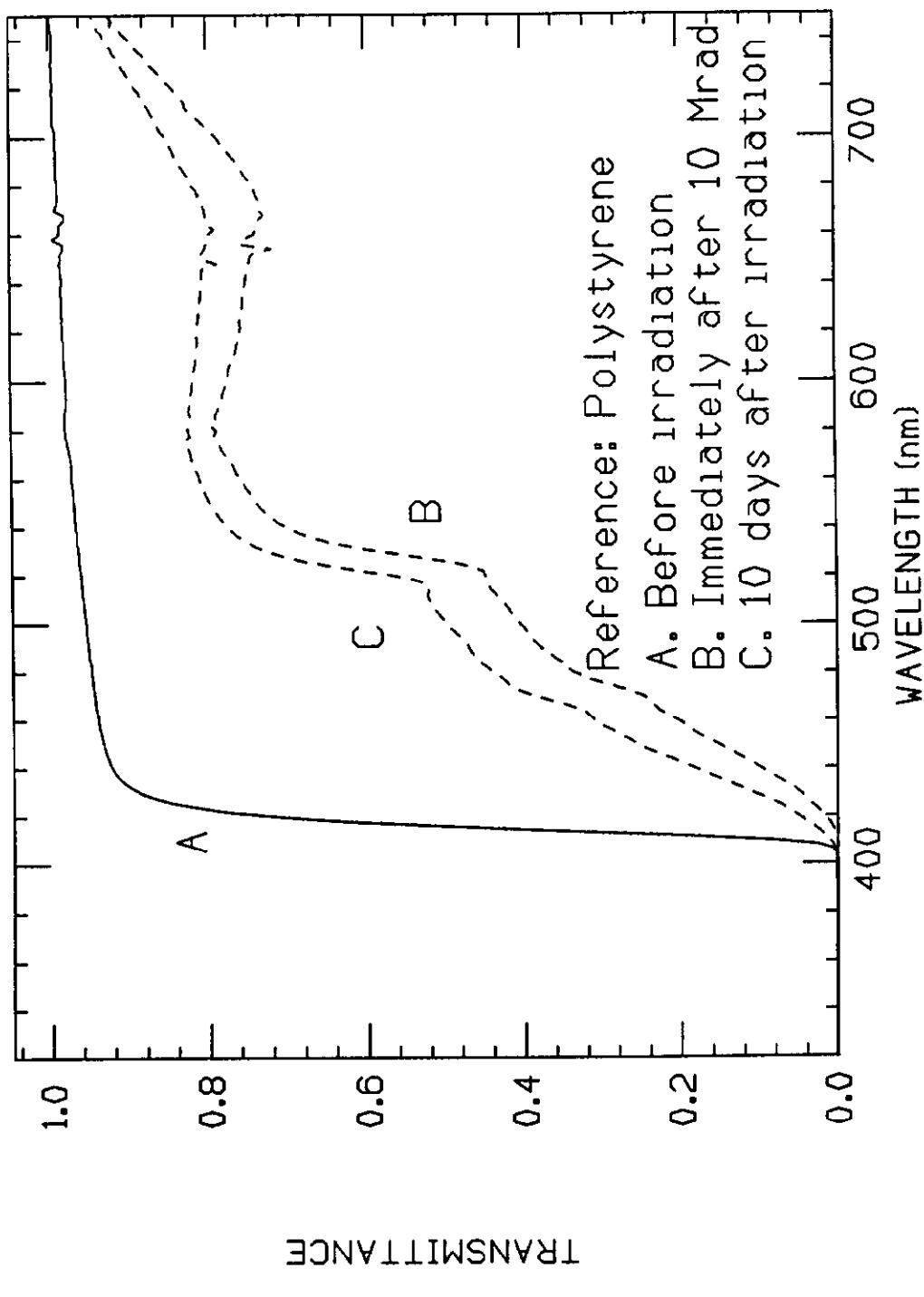
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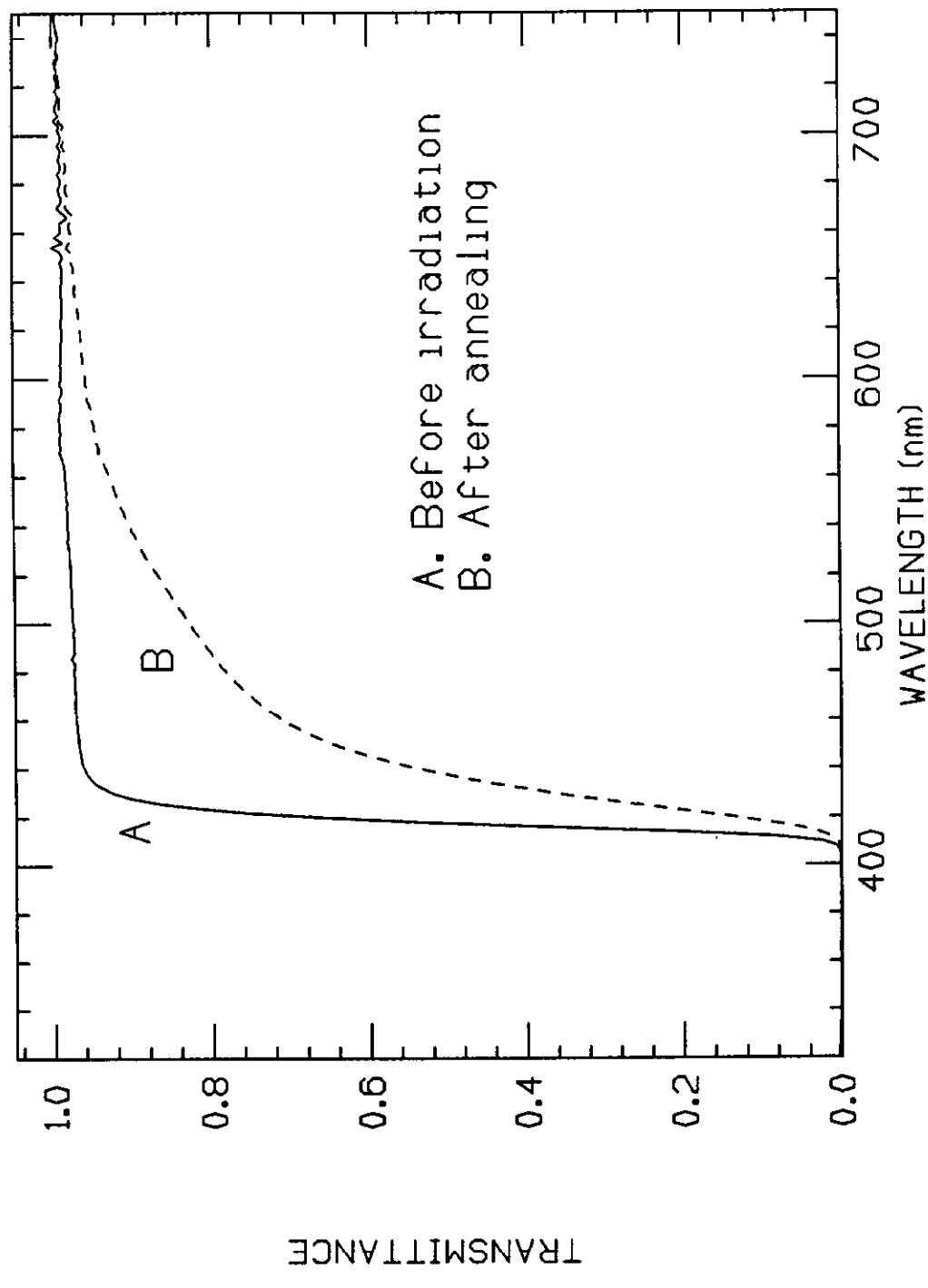
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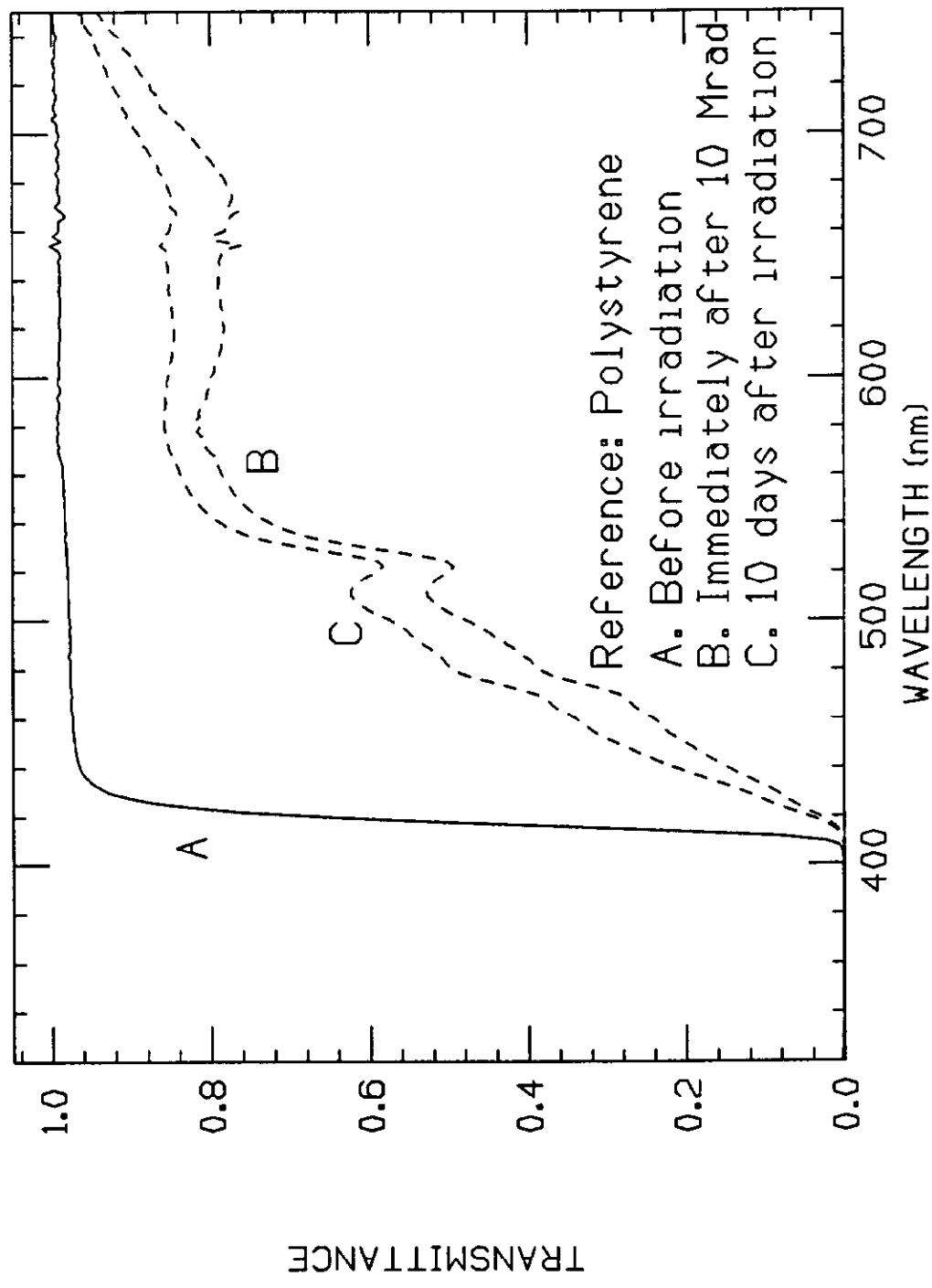
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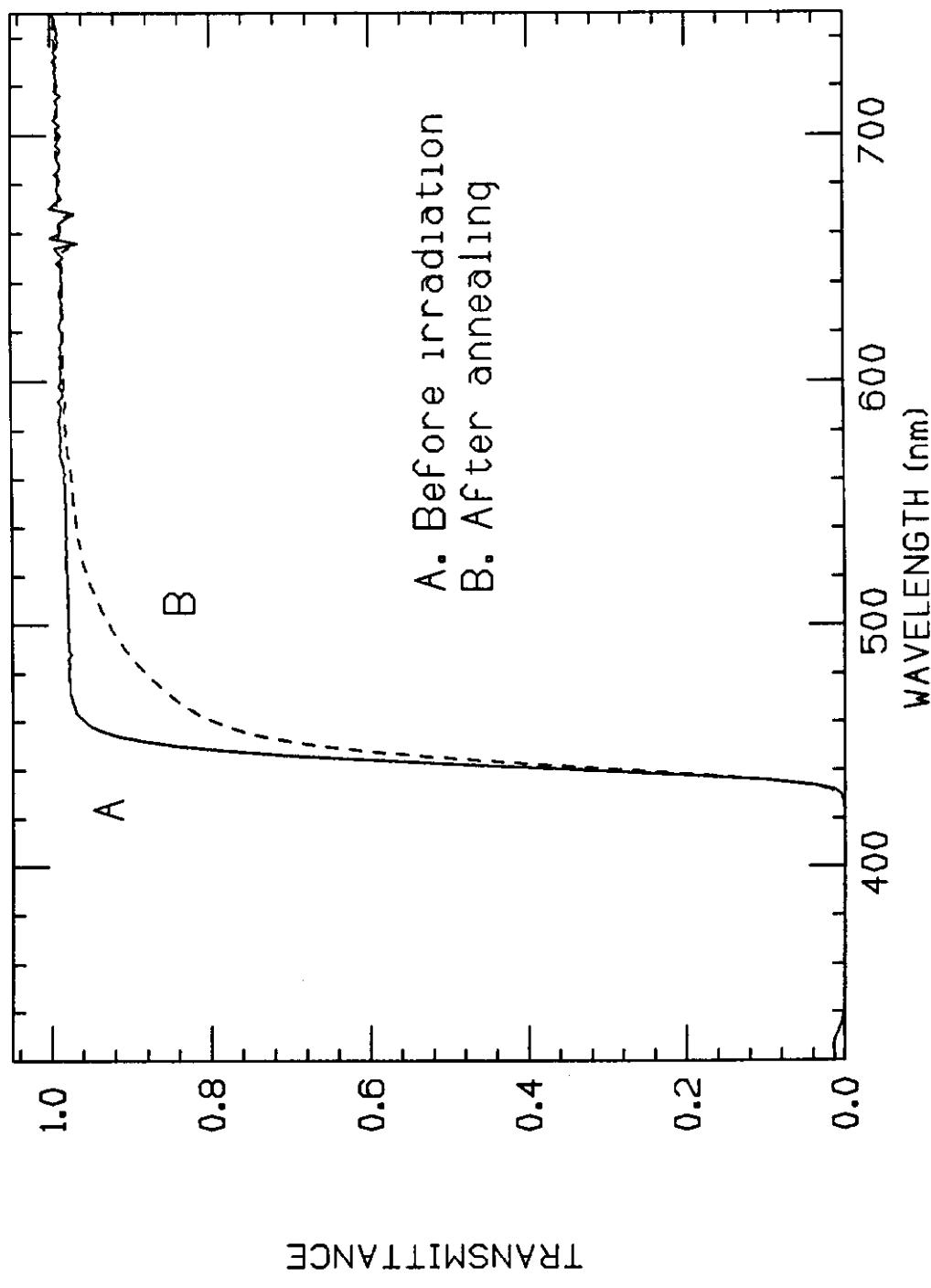
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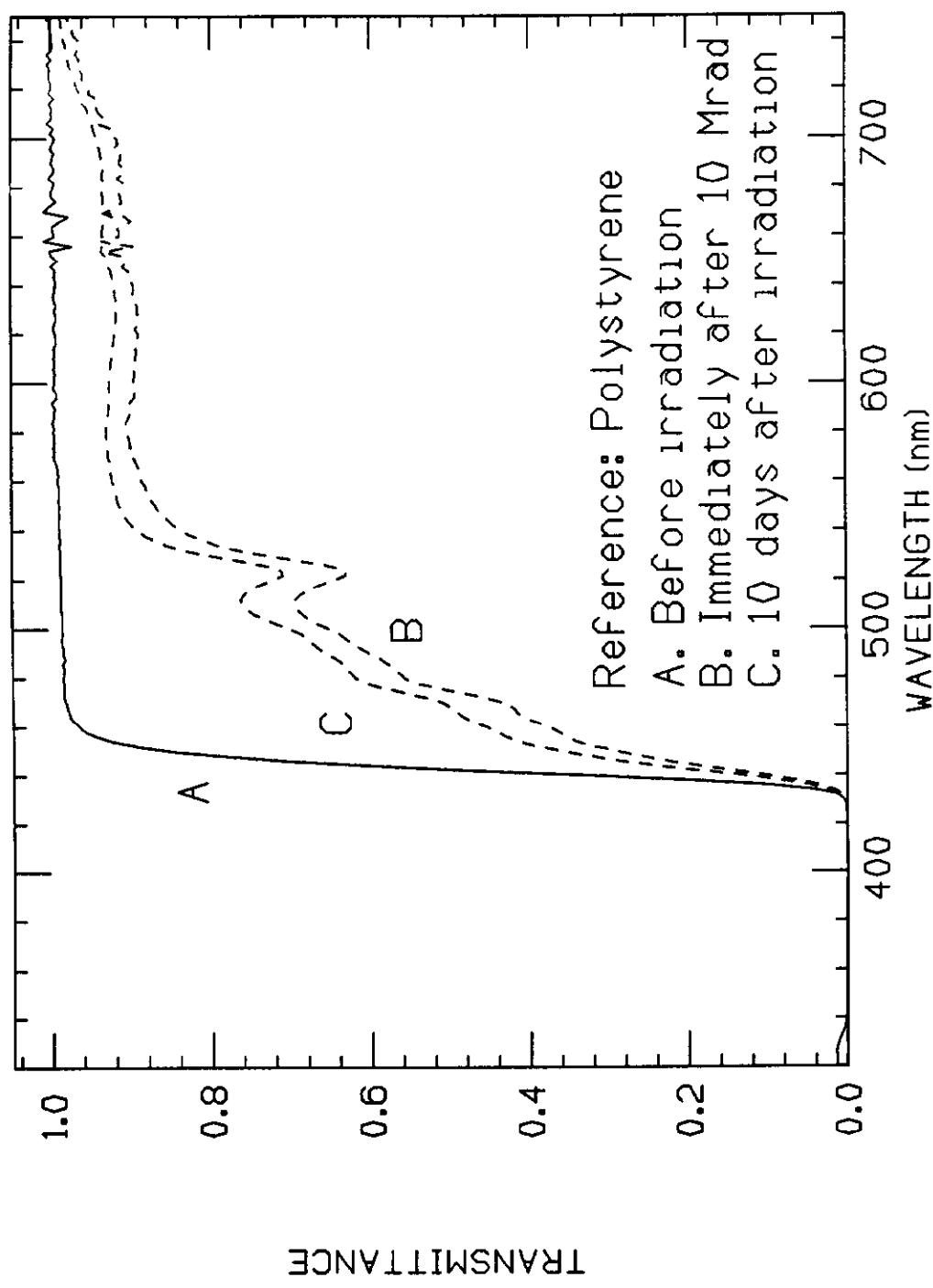
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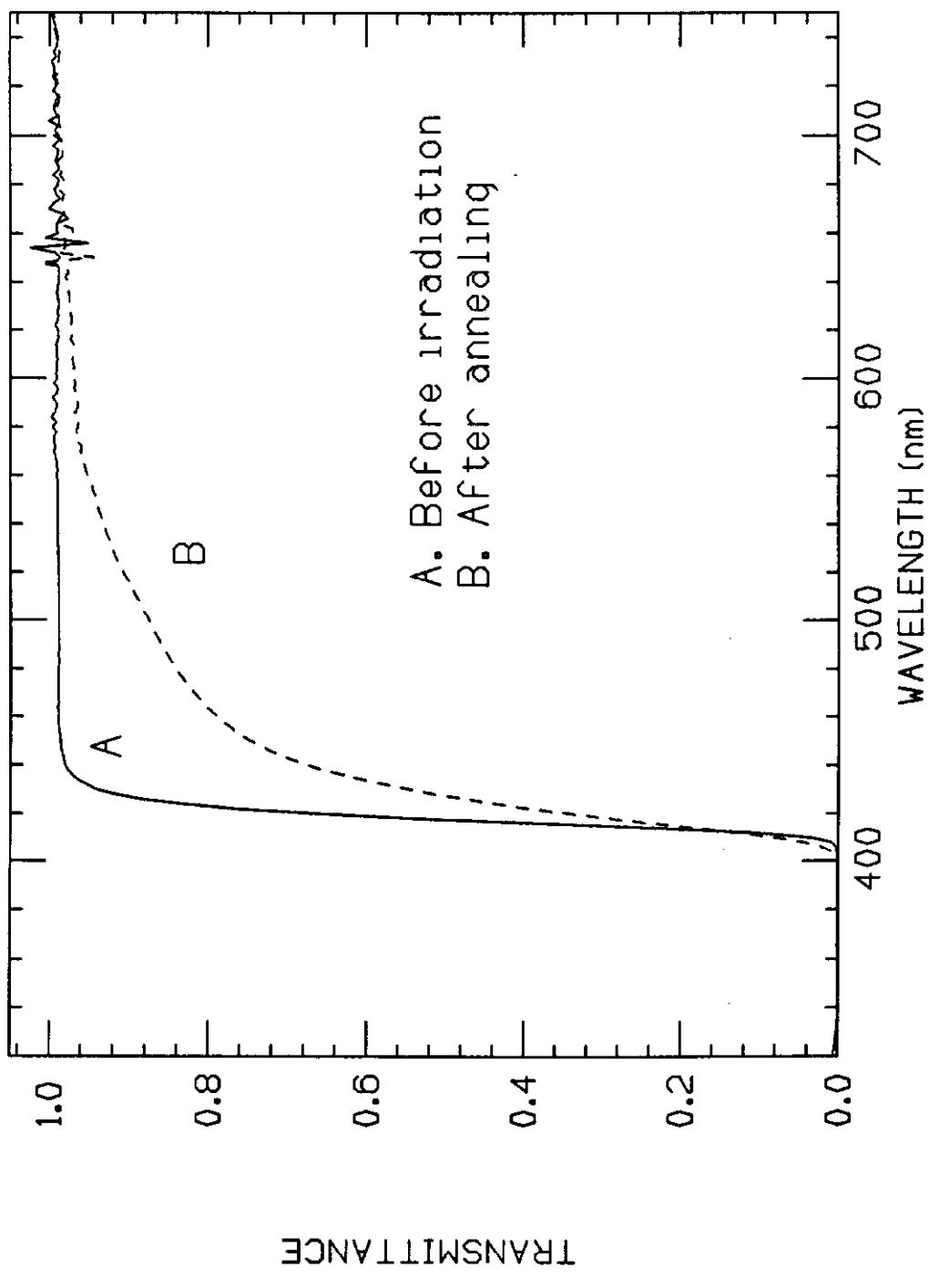
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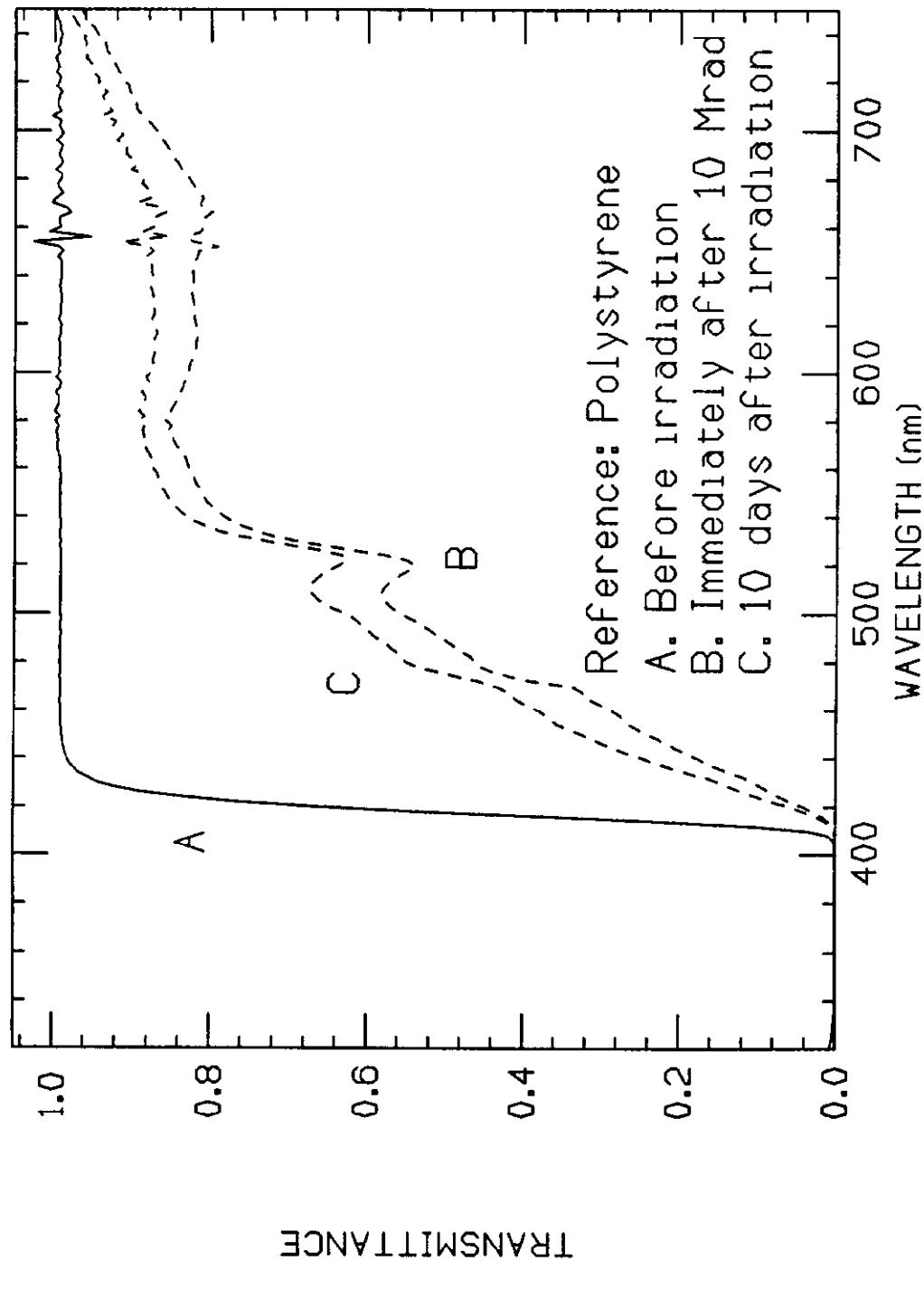
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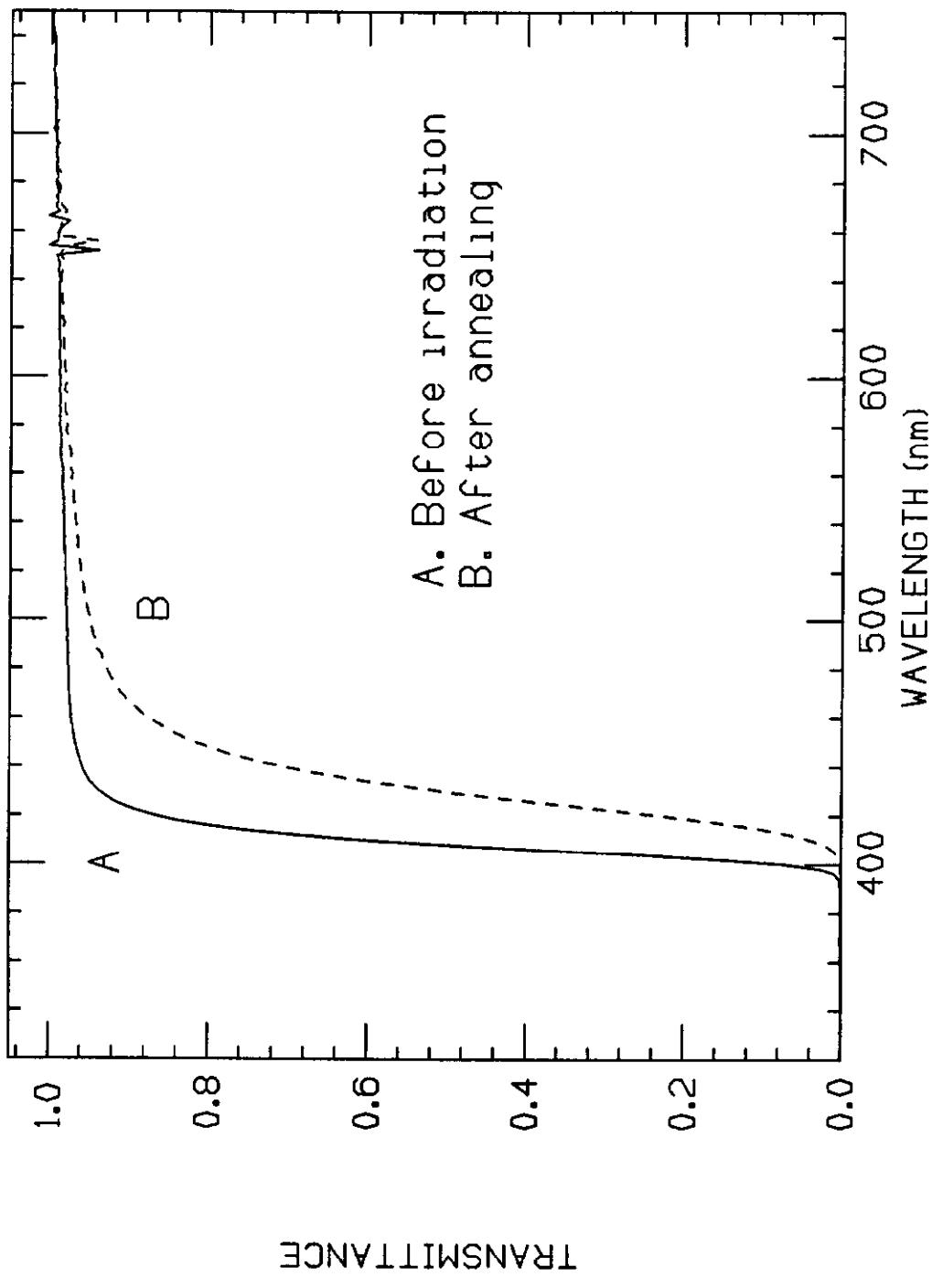
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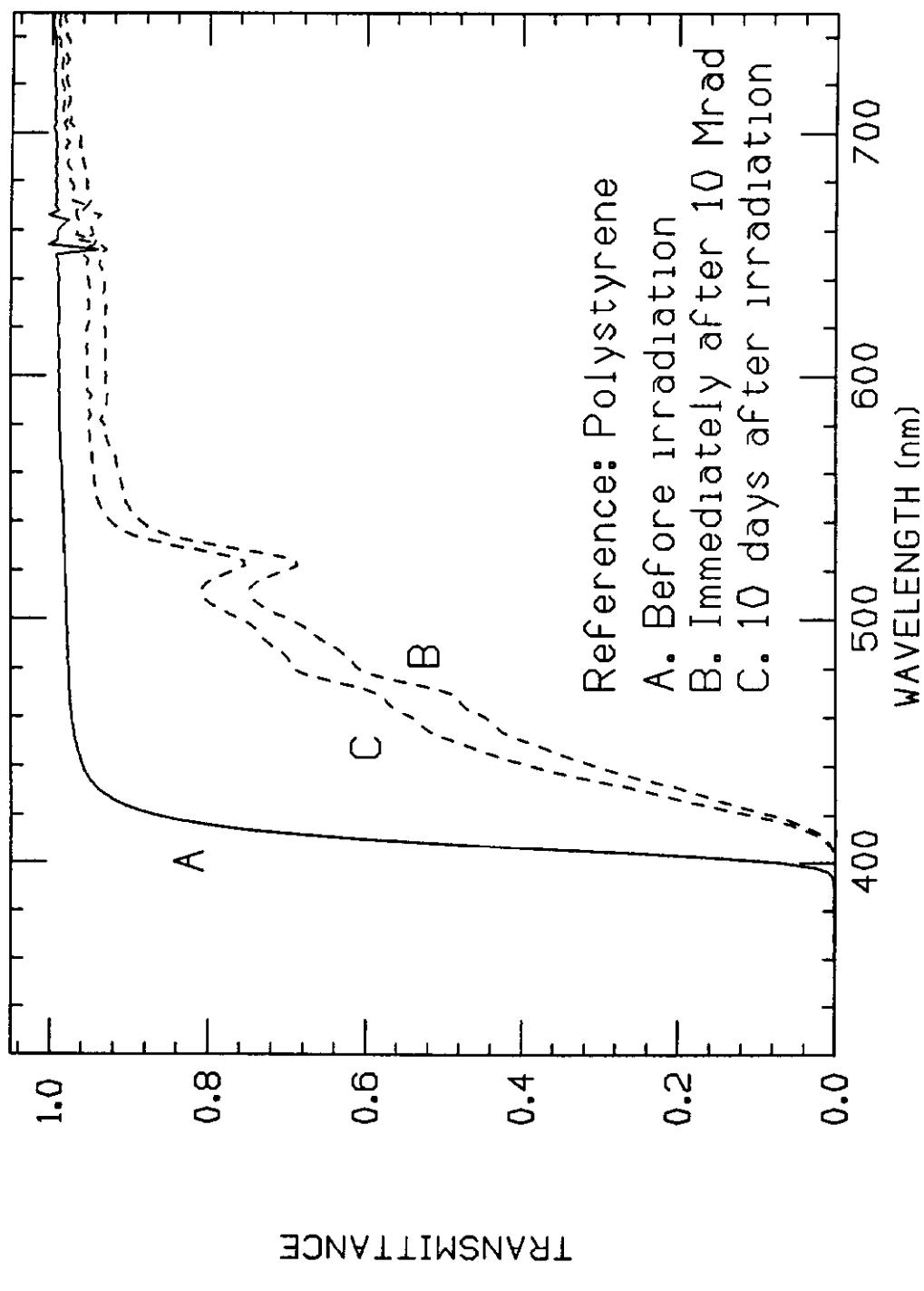
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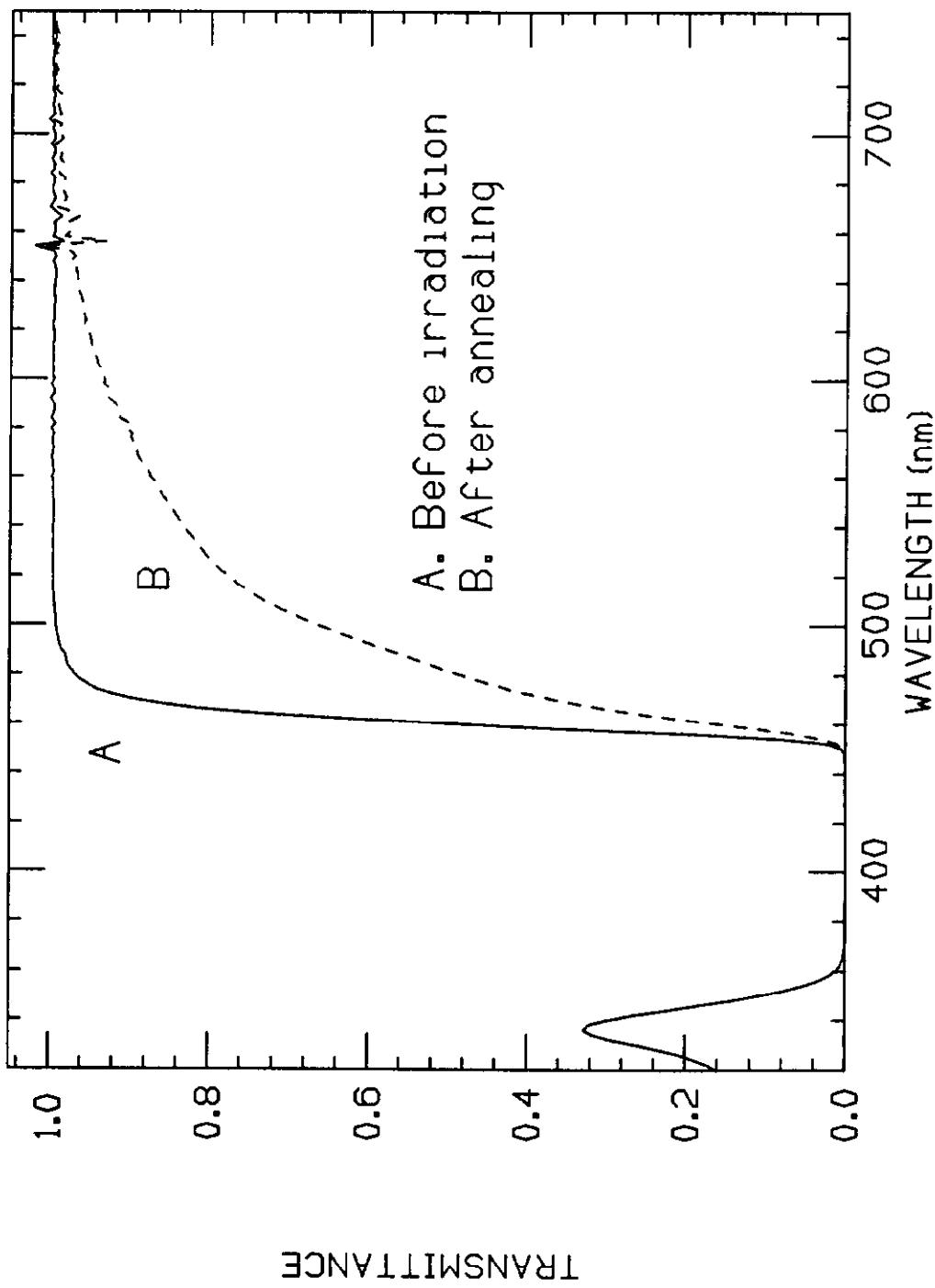
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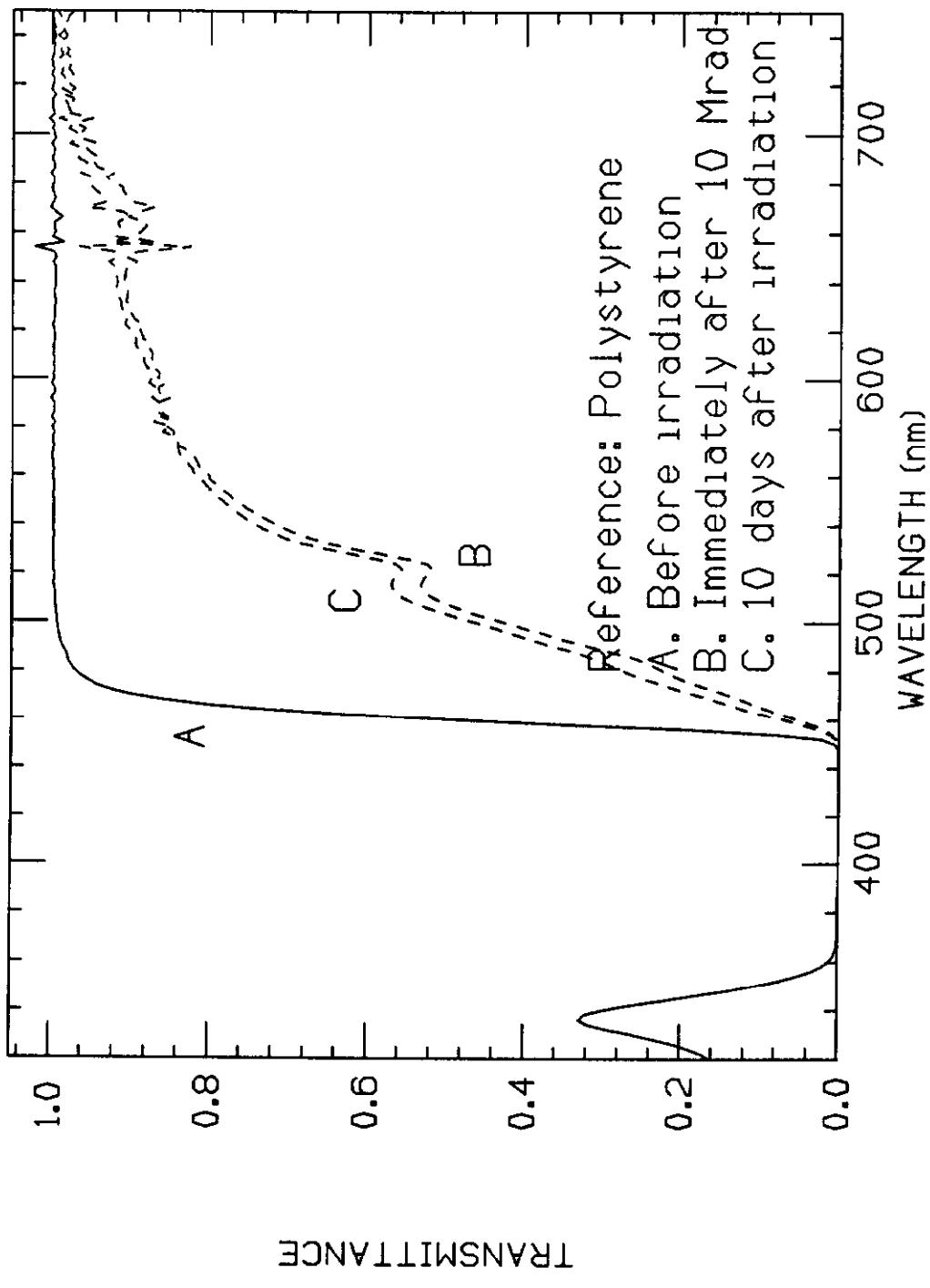
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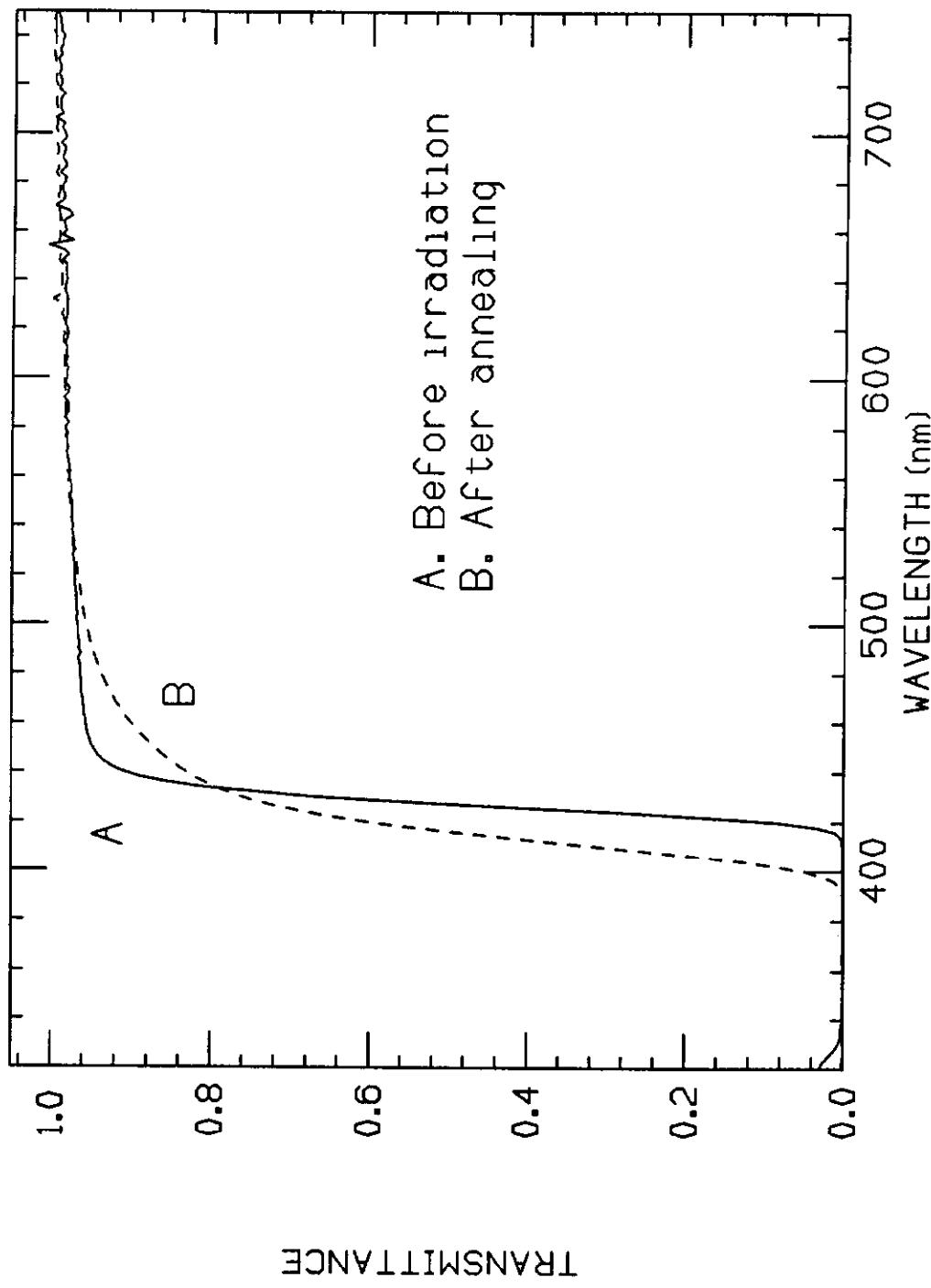
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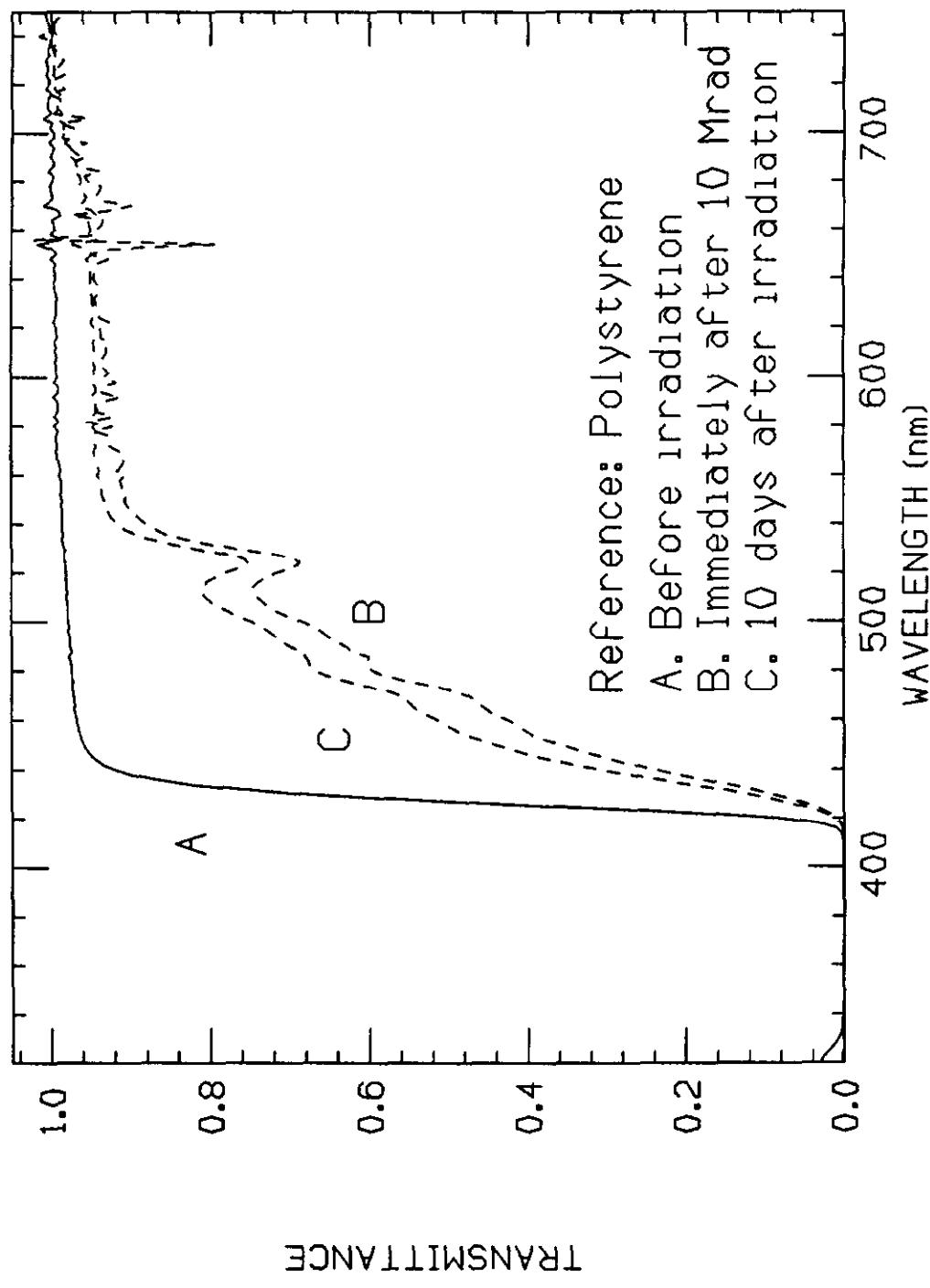
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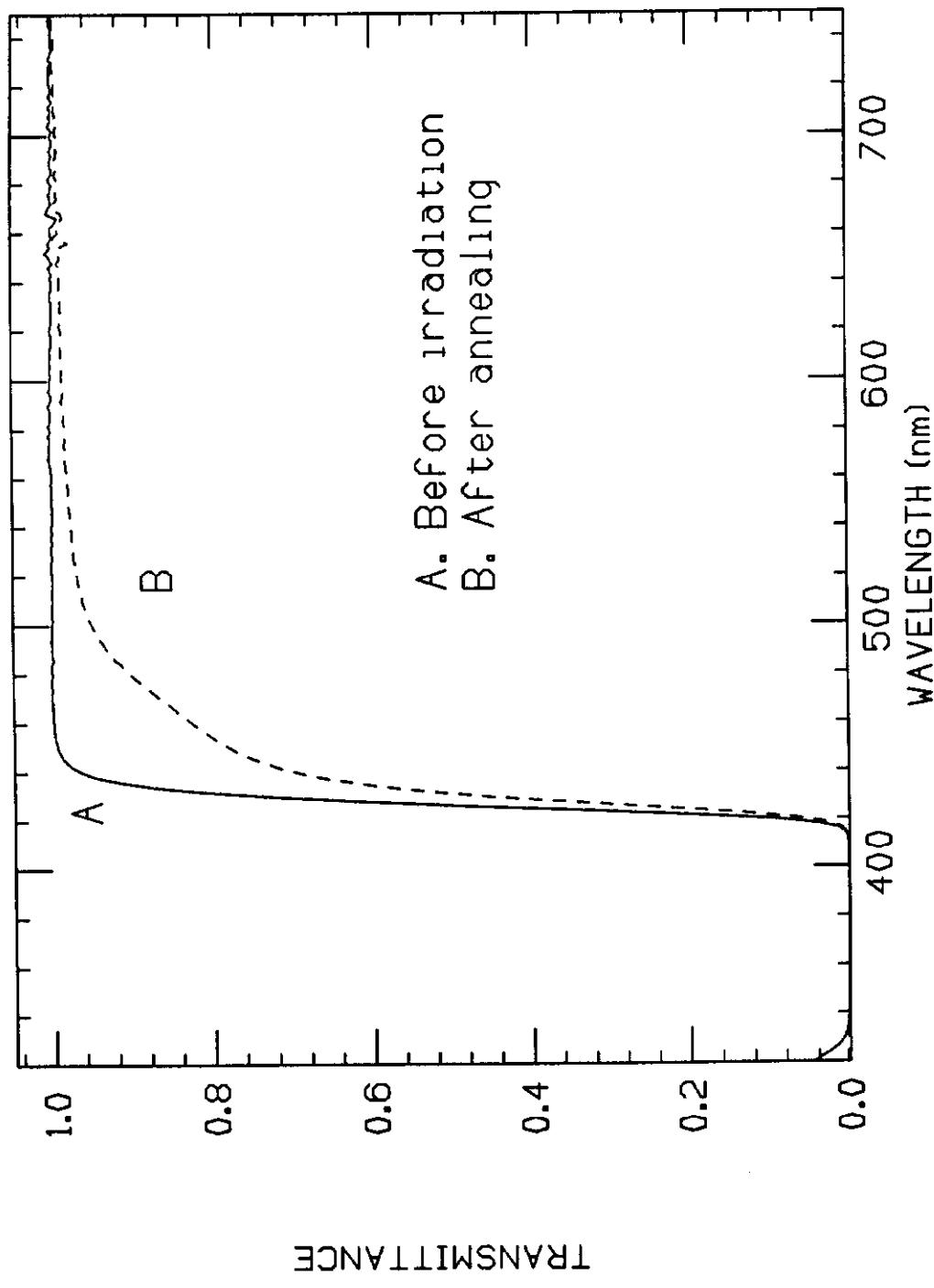
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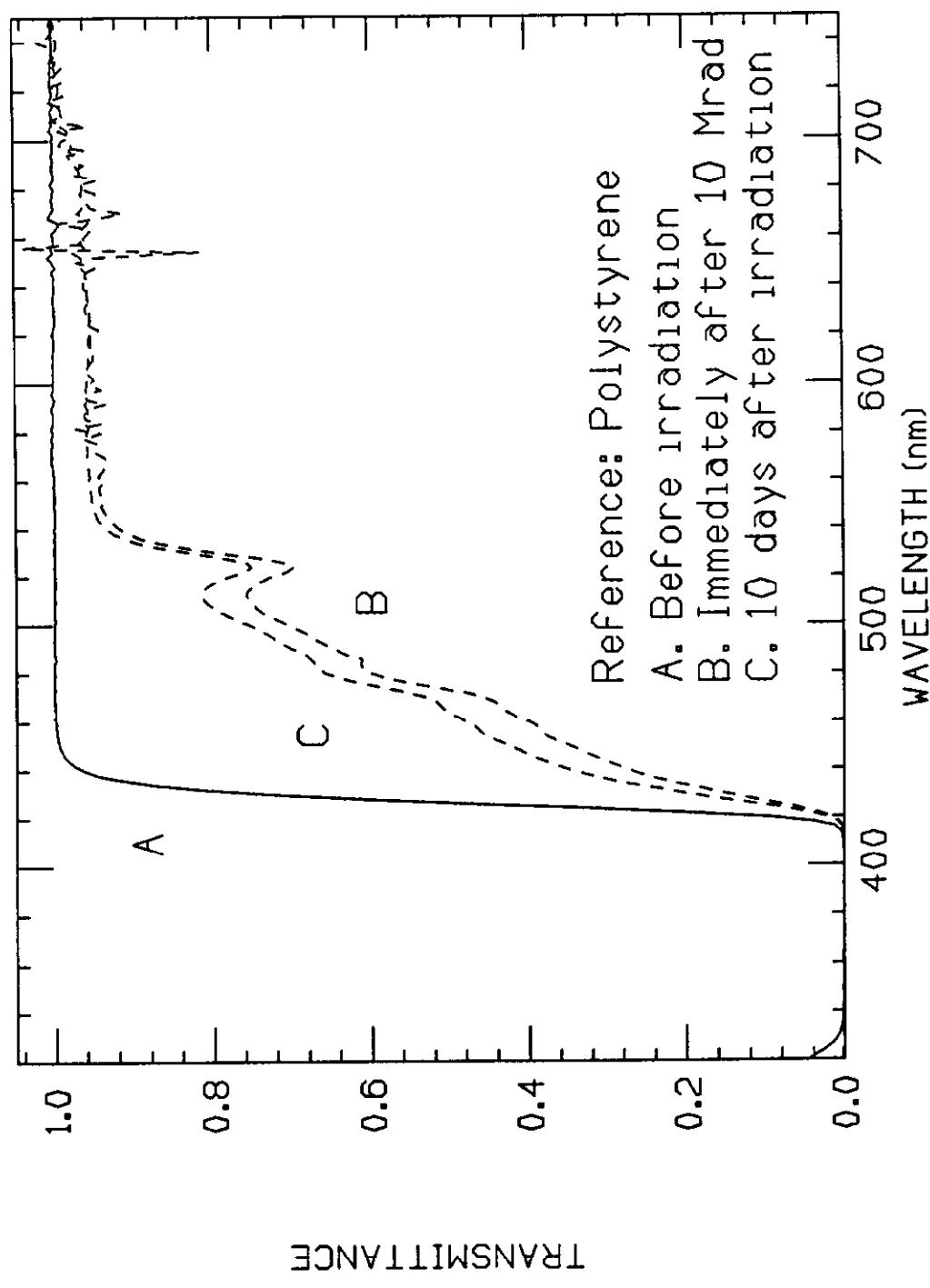
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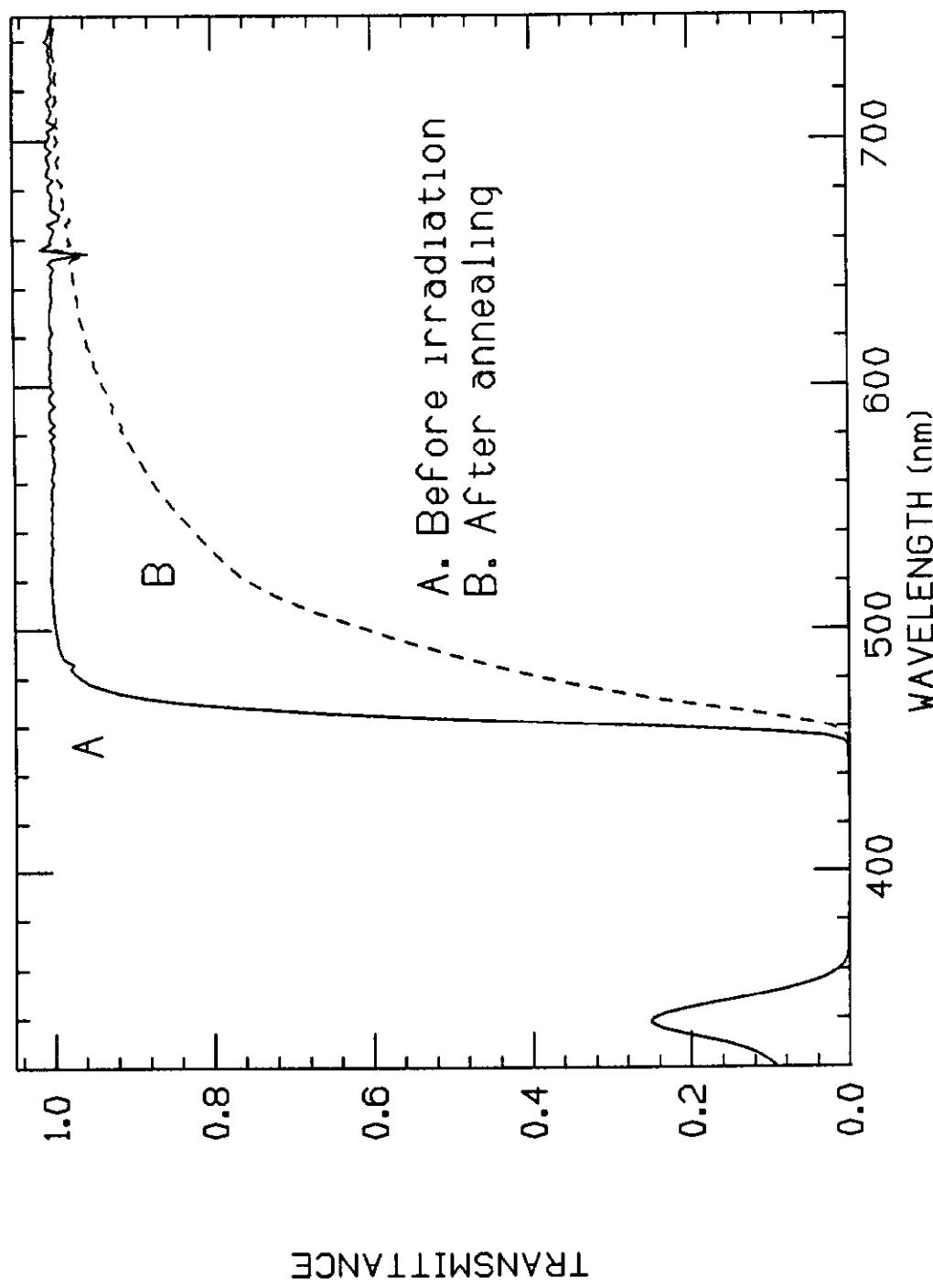
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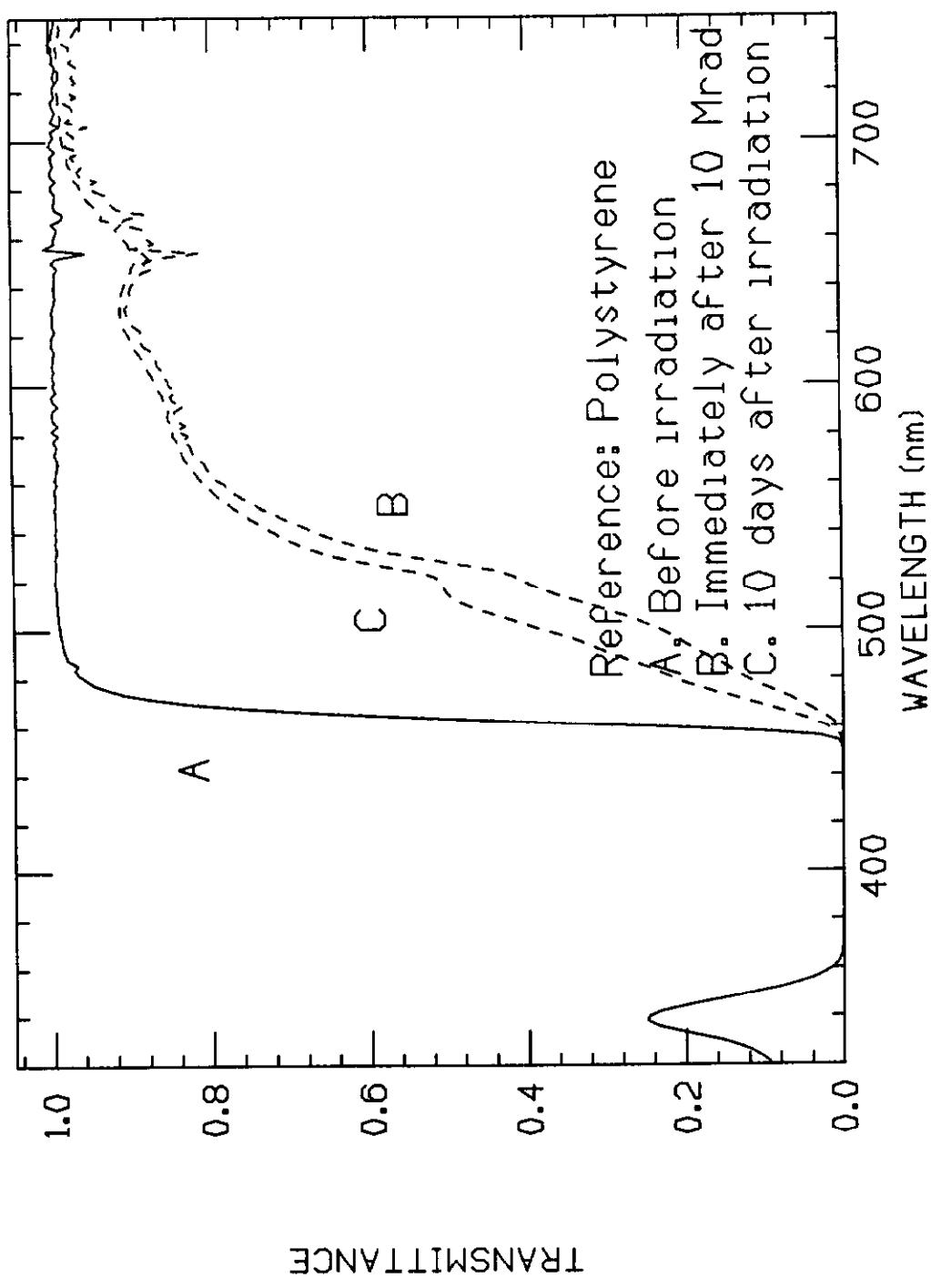
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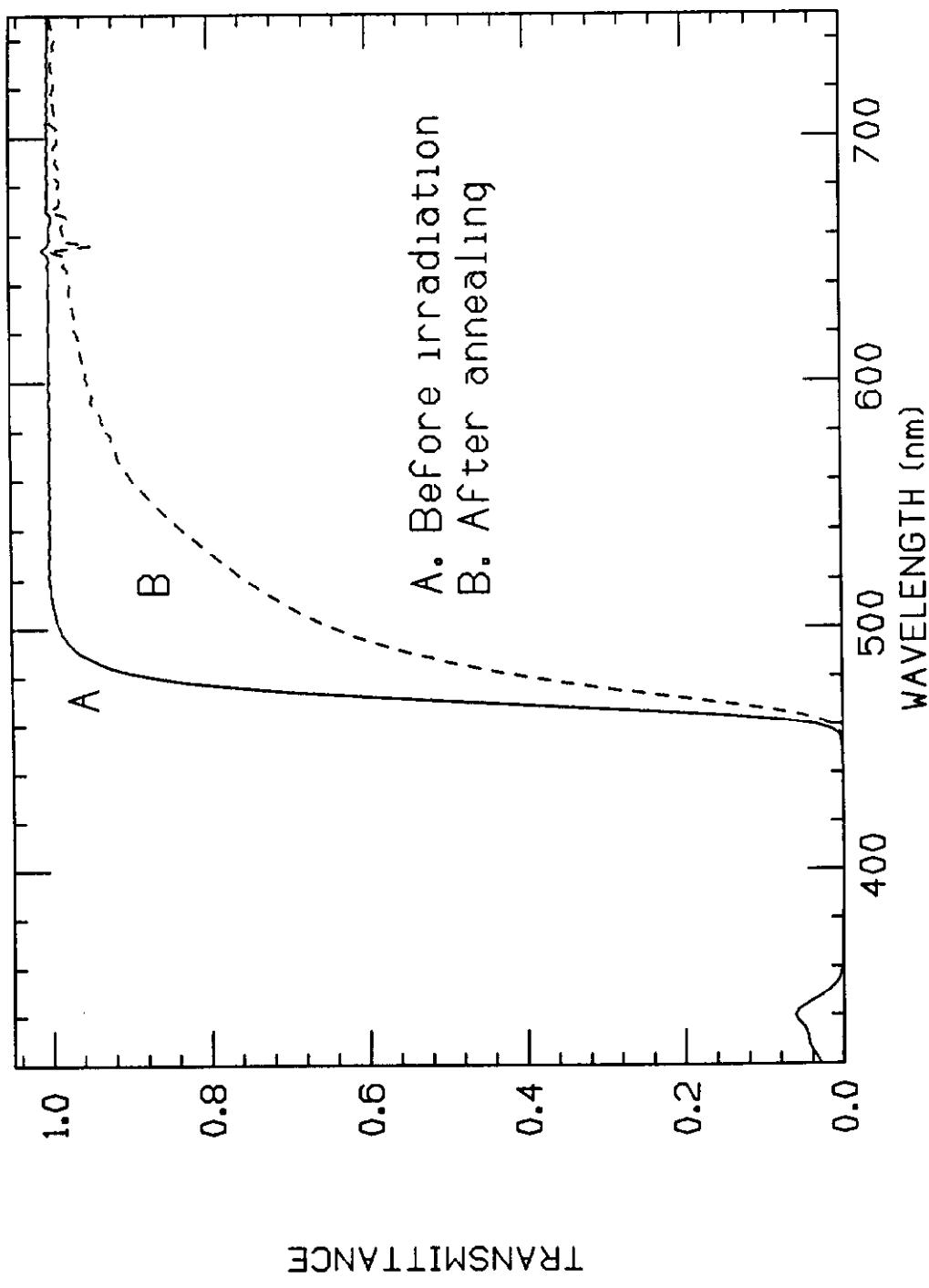
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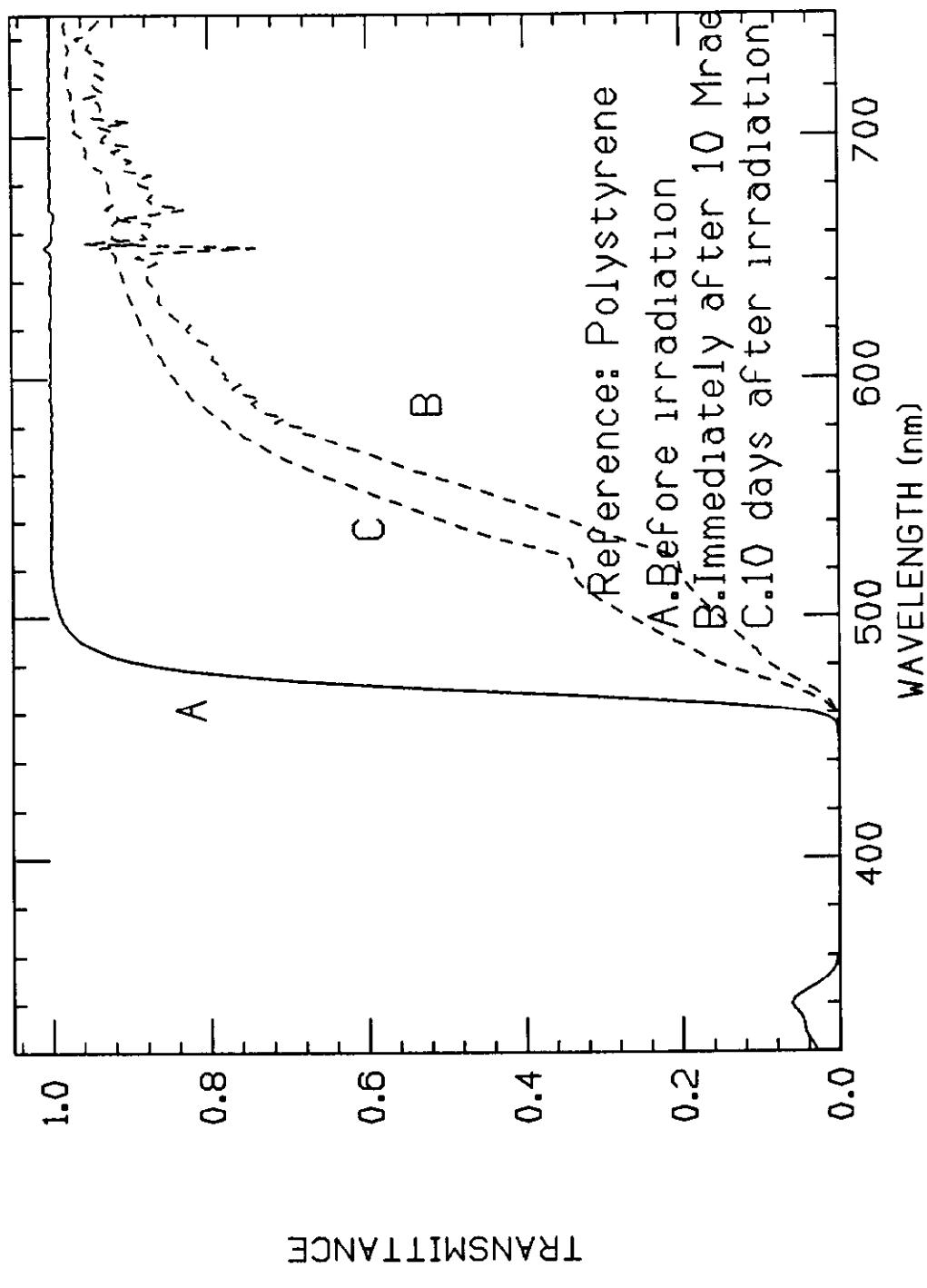
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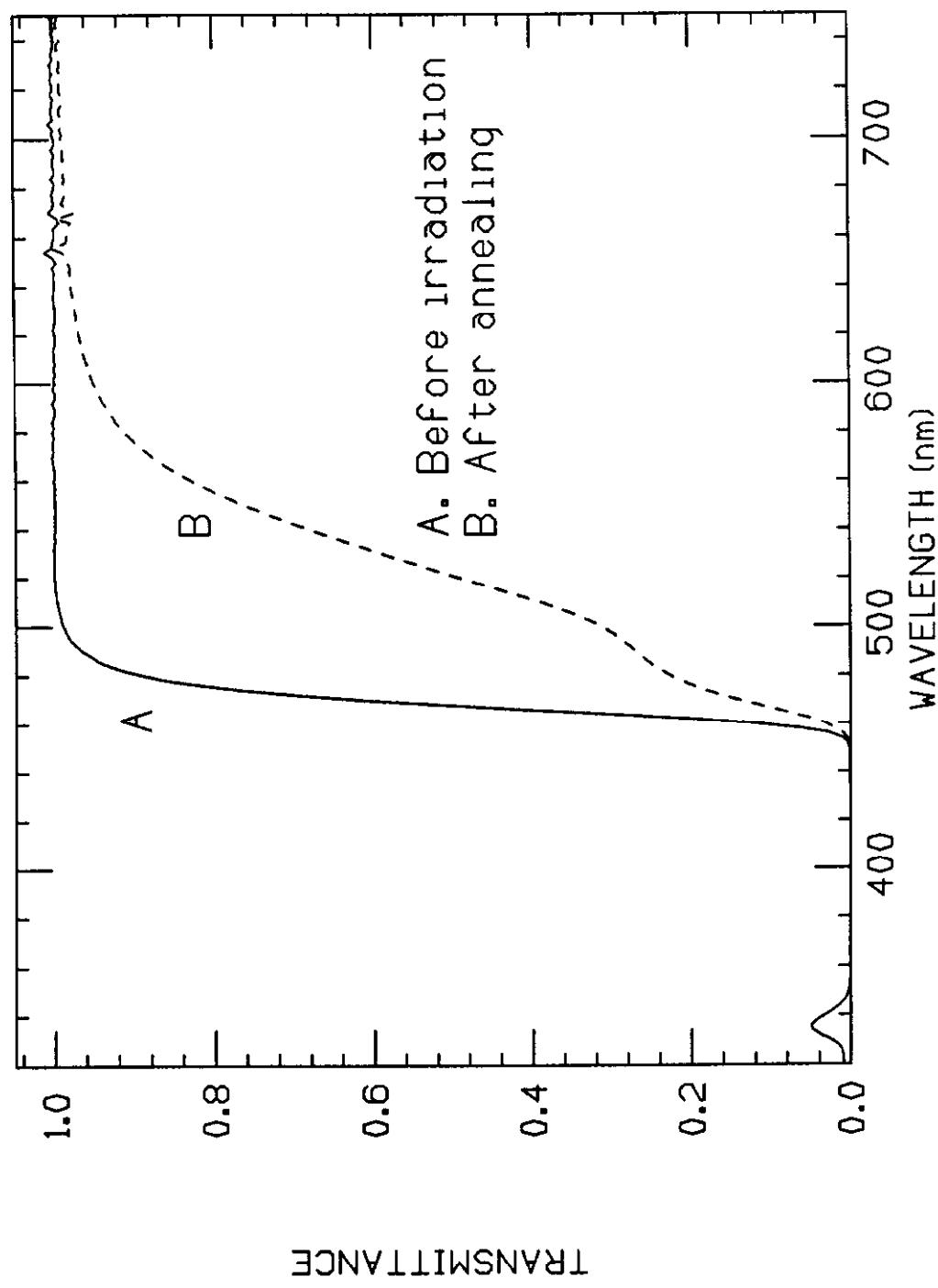
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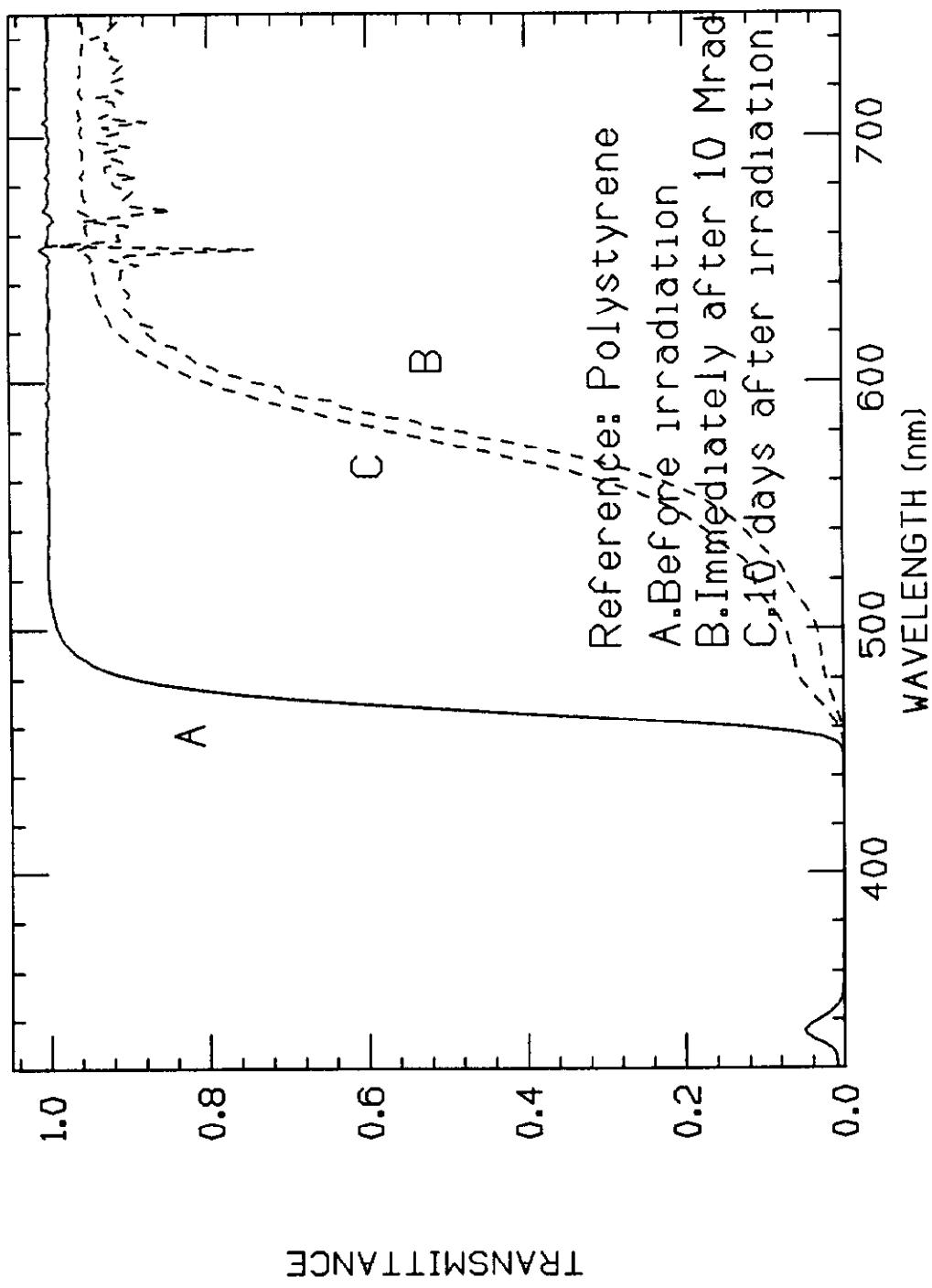
0.02% C510 - HIGH DOSE RATE IRRADIATION IN AIR



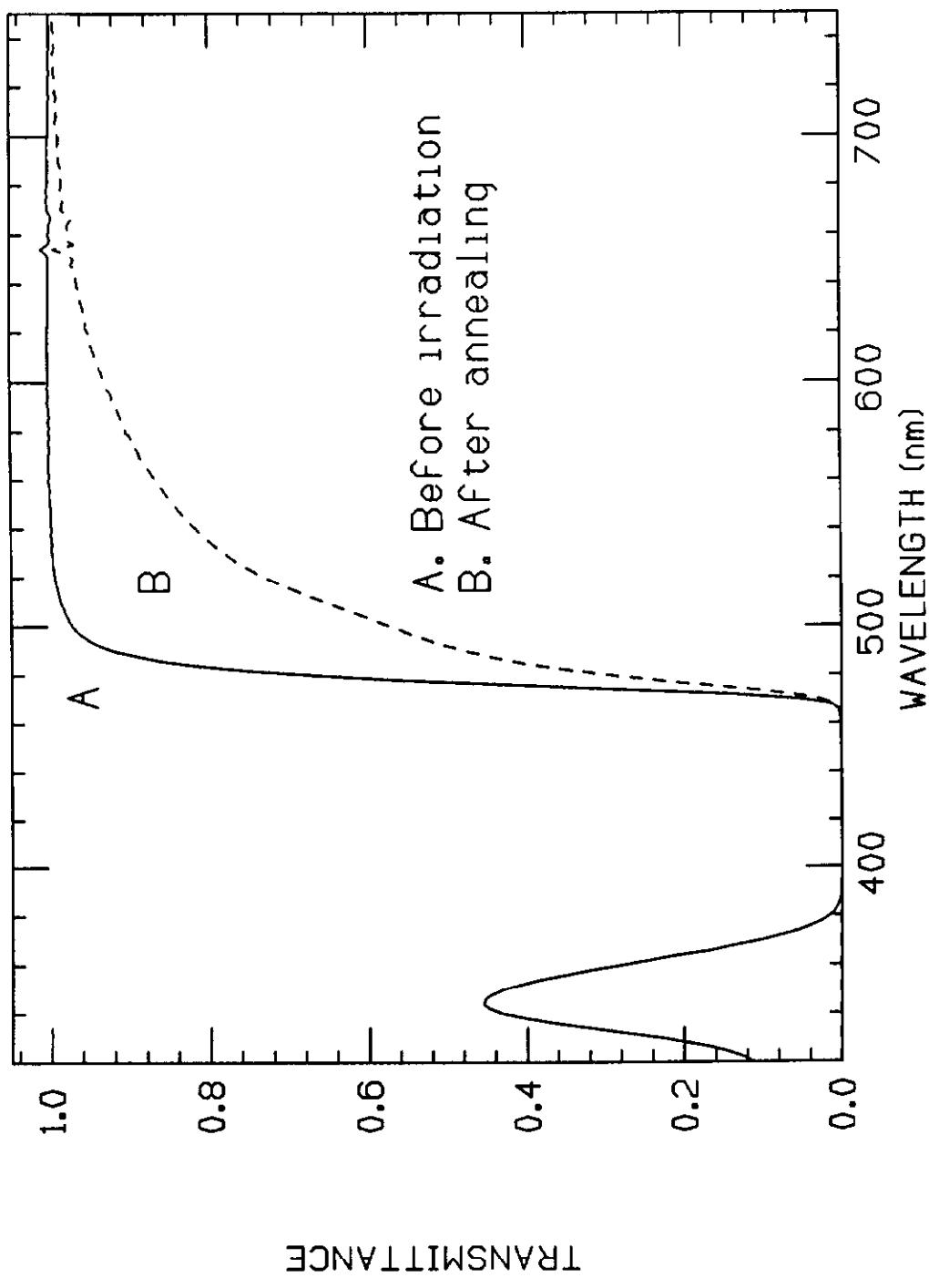
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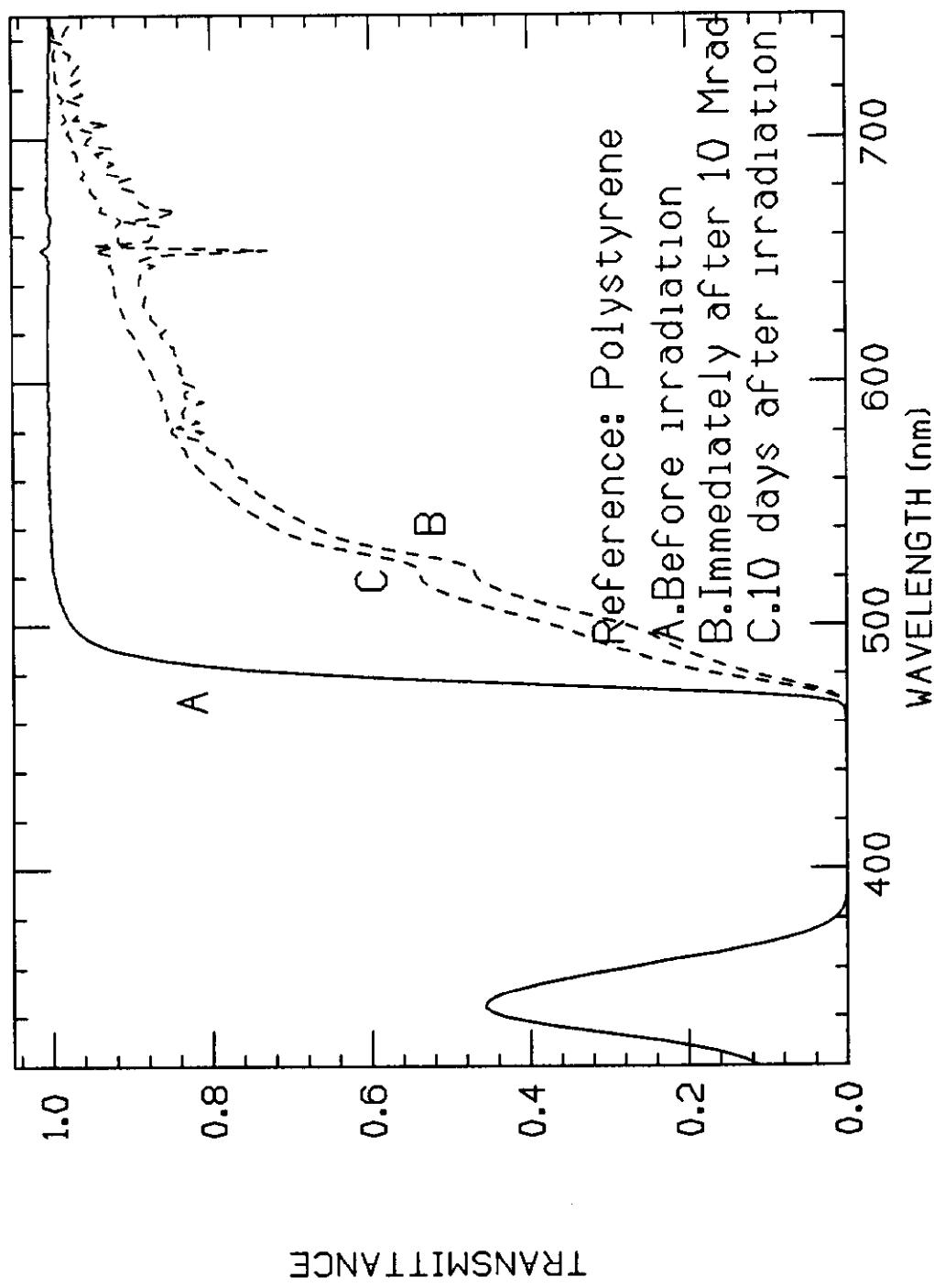
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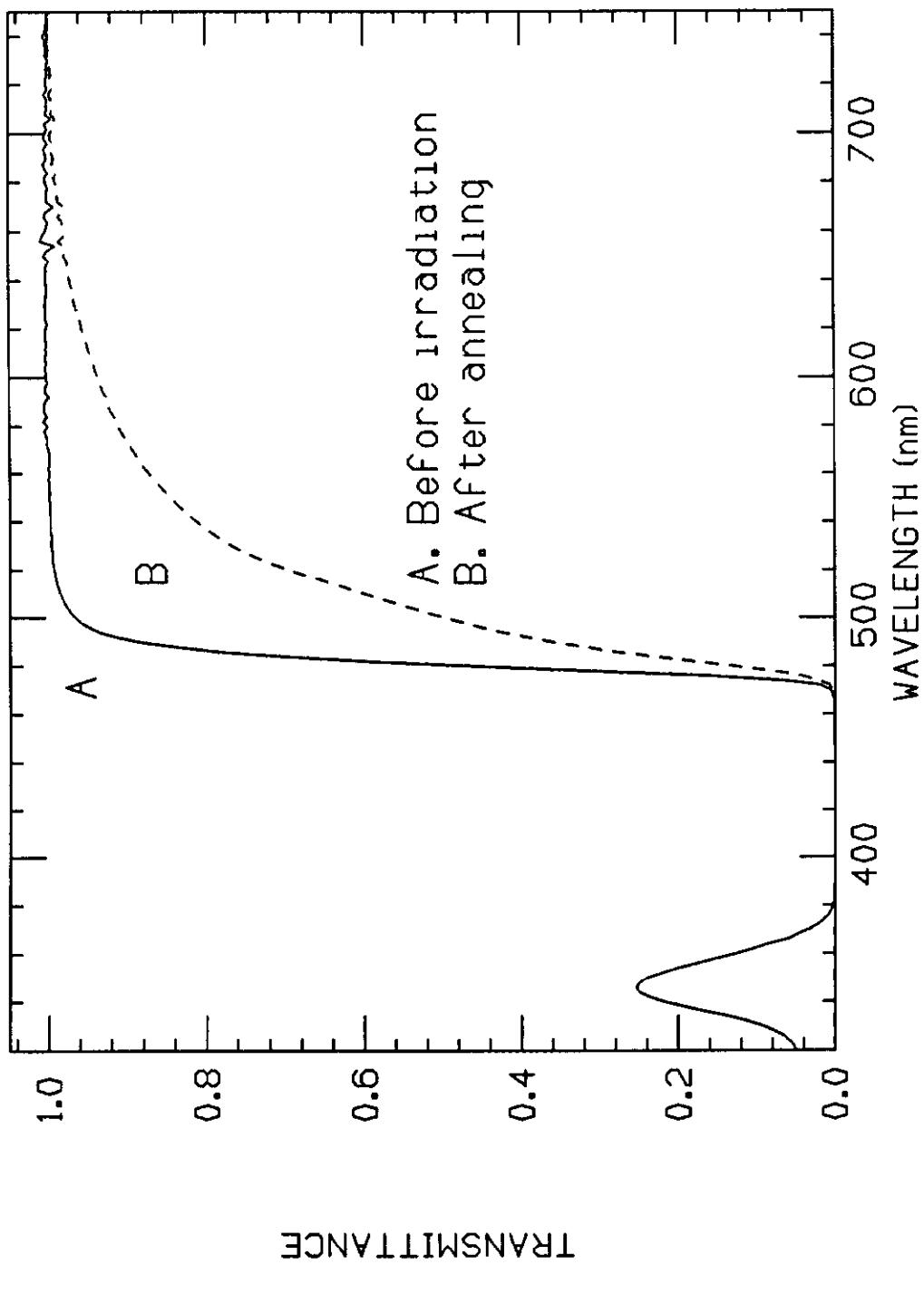
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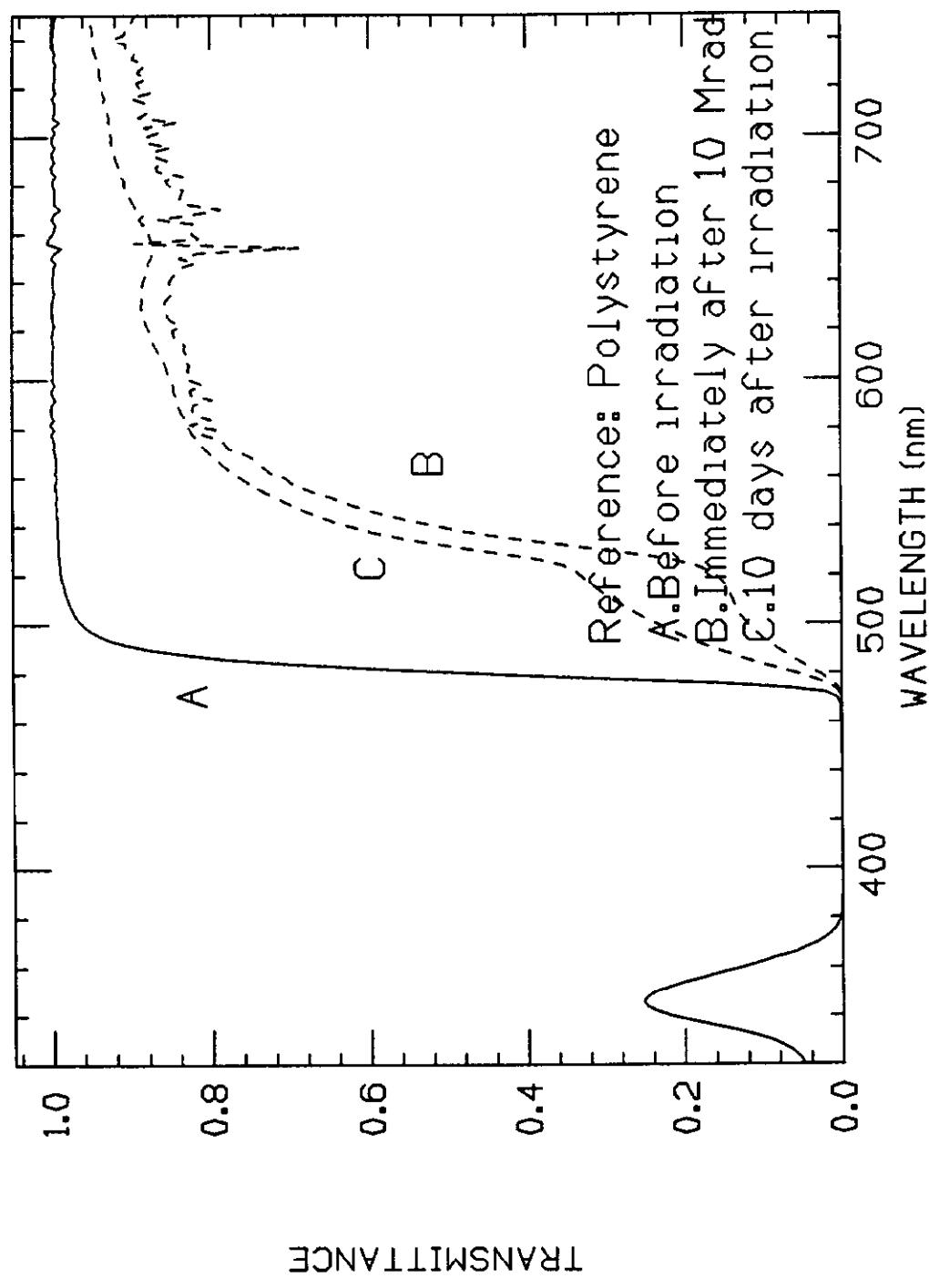
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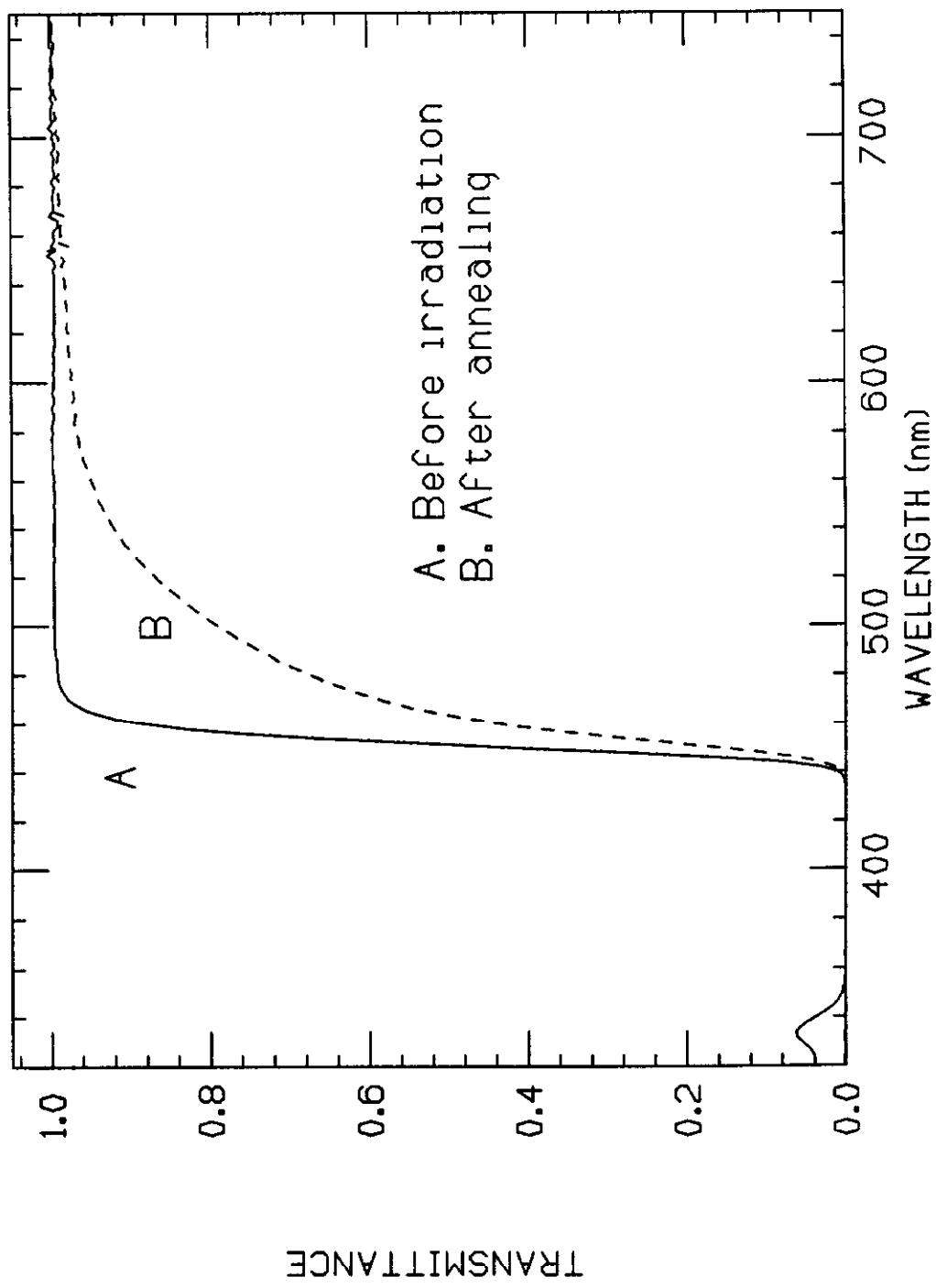
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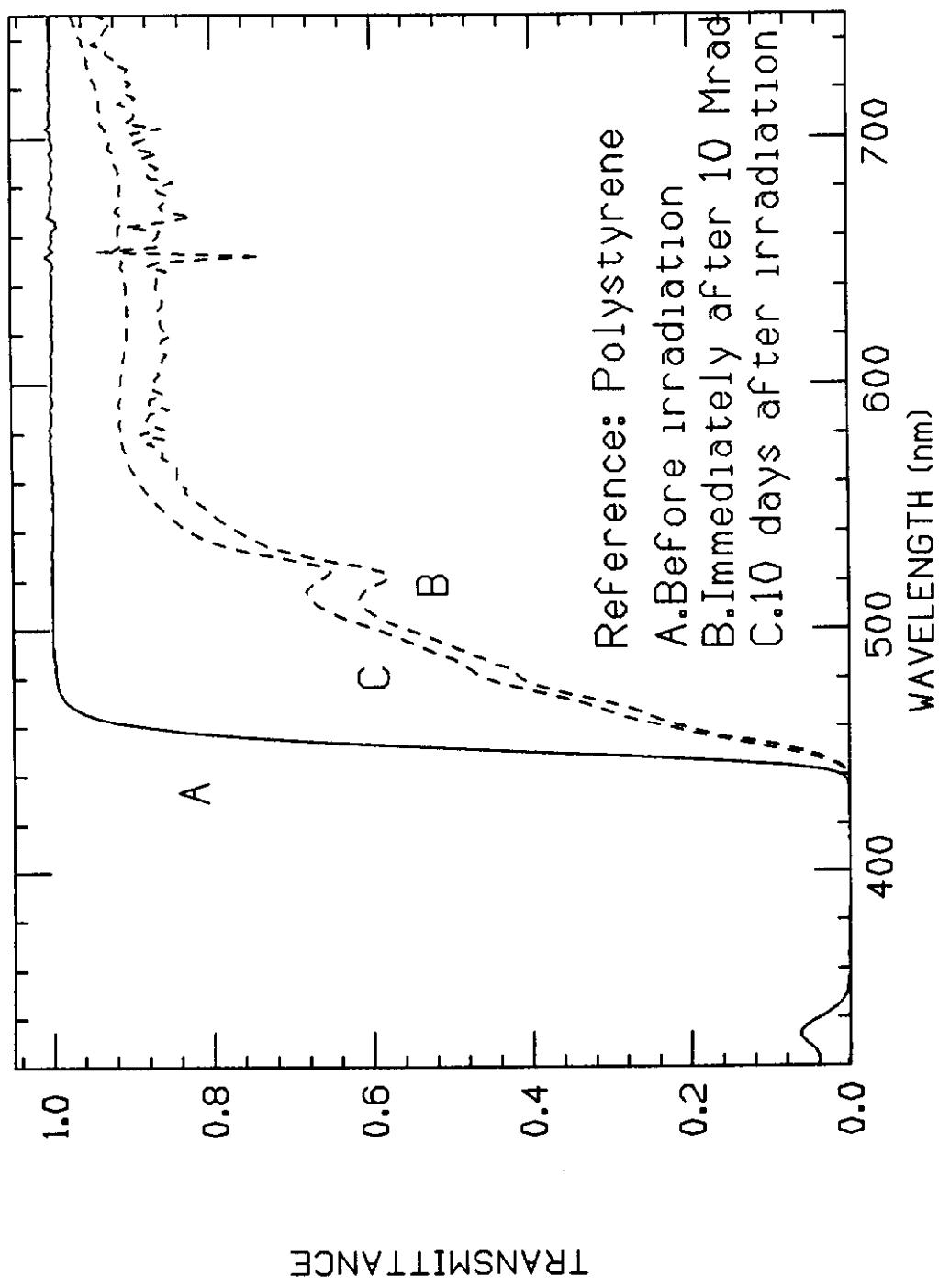
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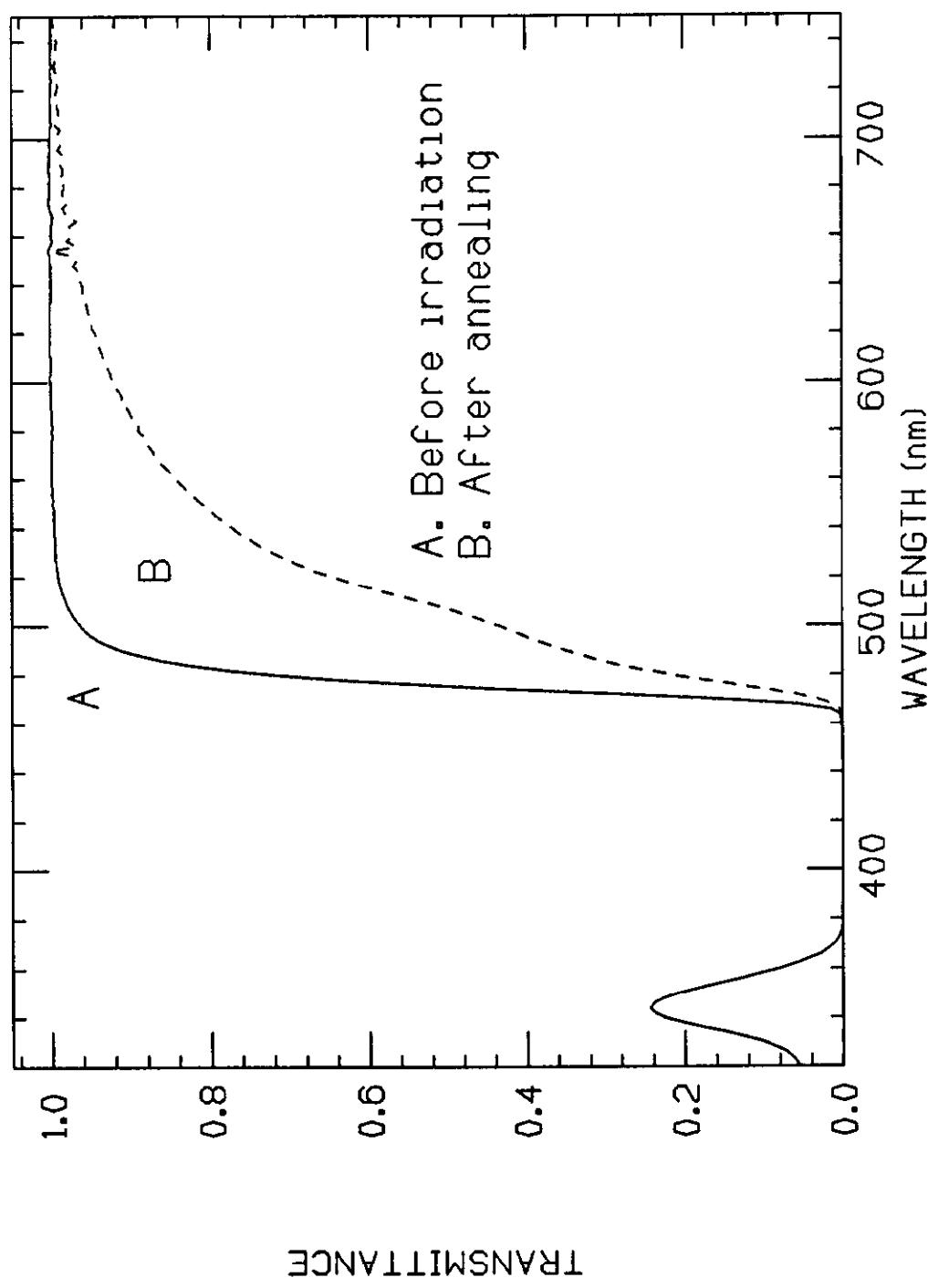
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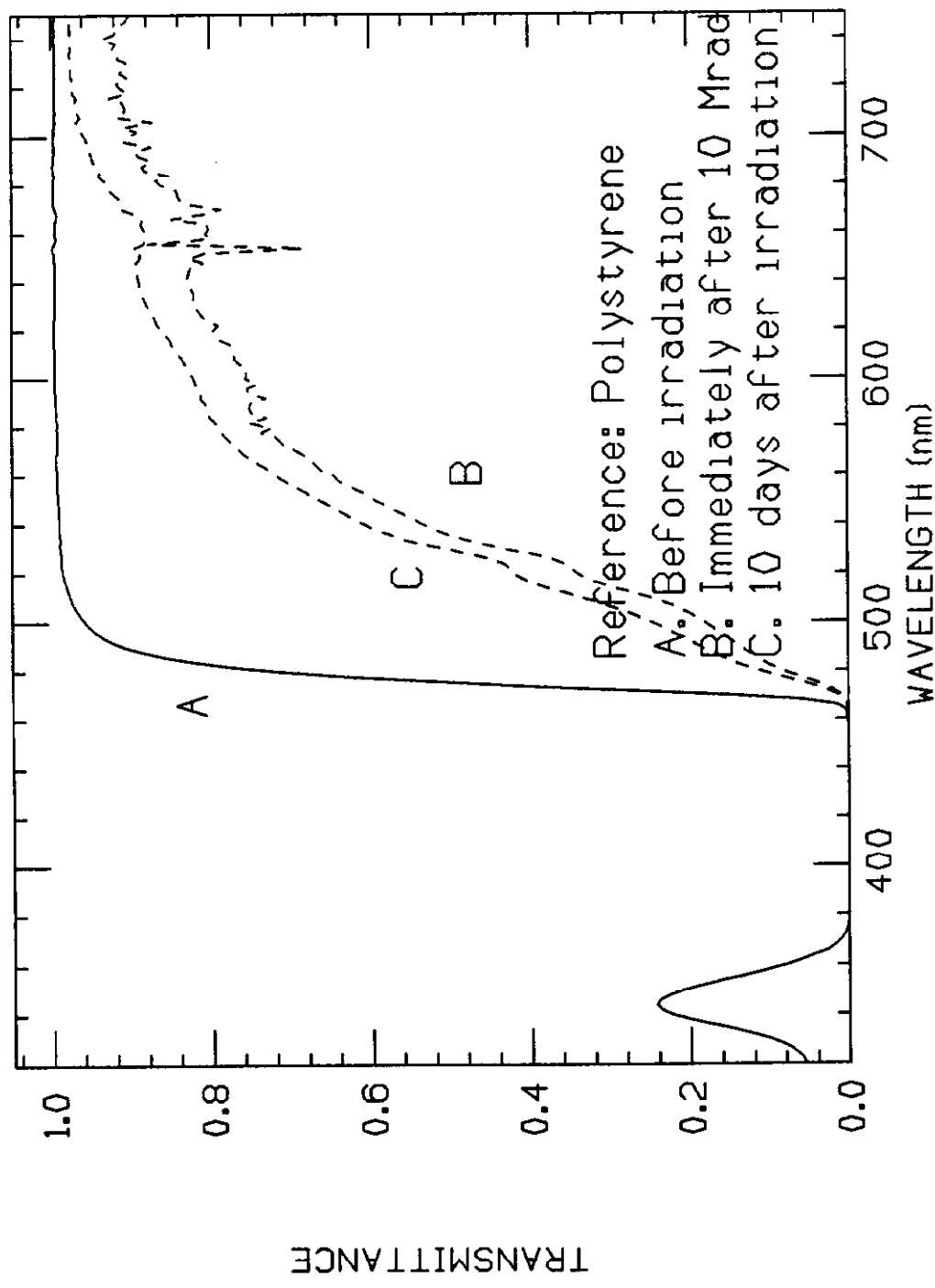
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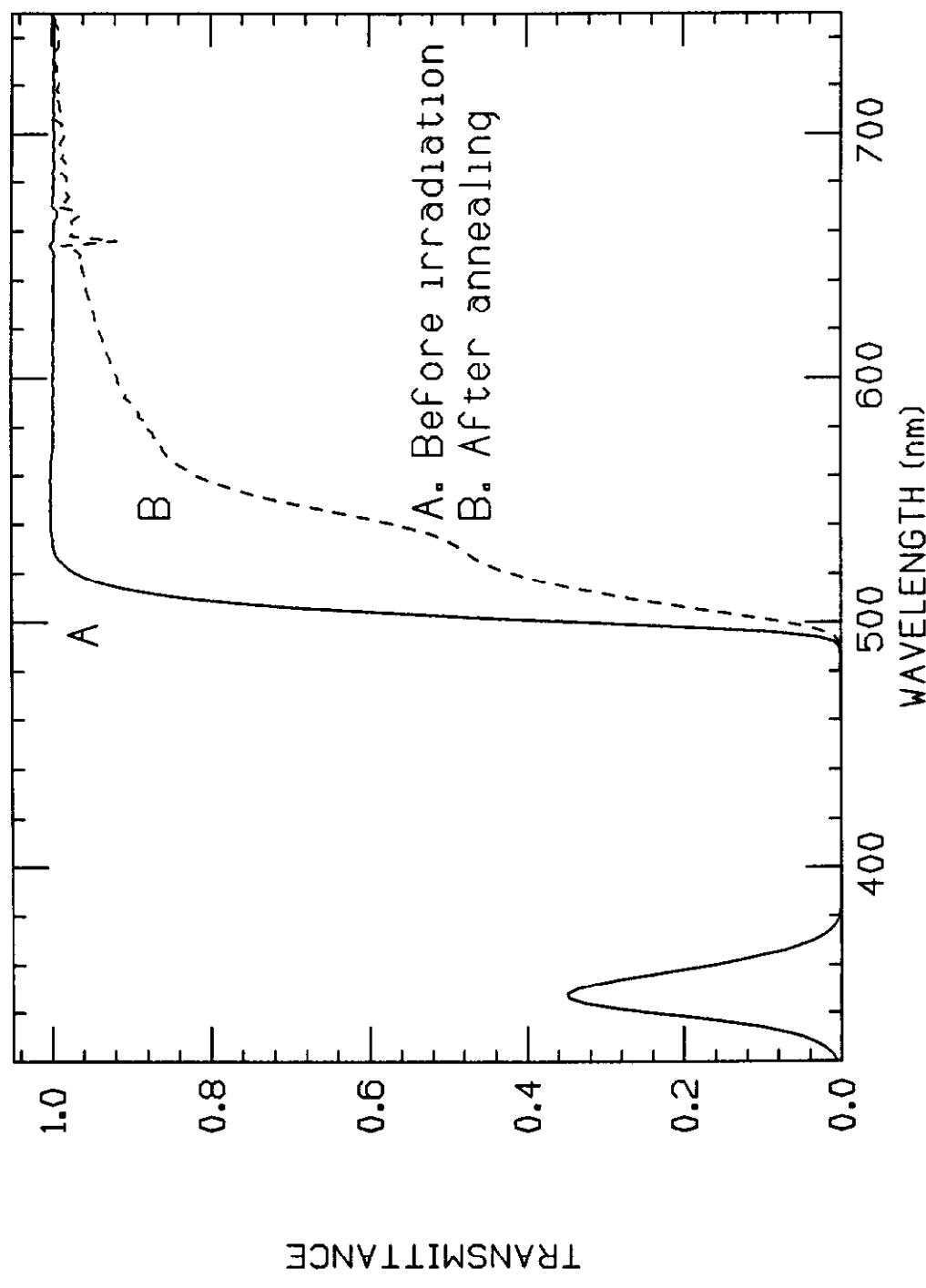
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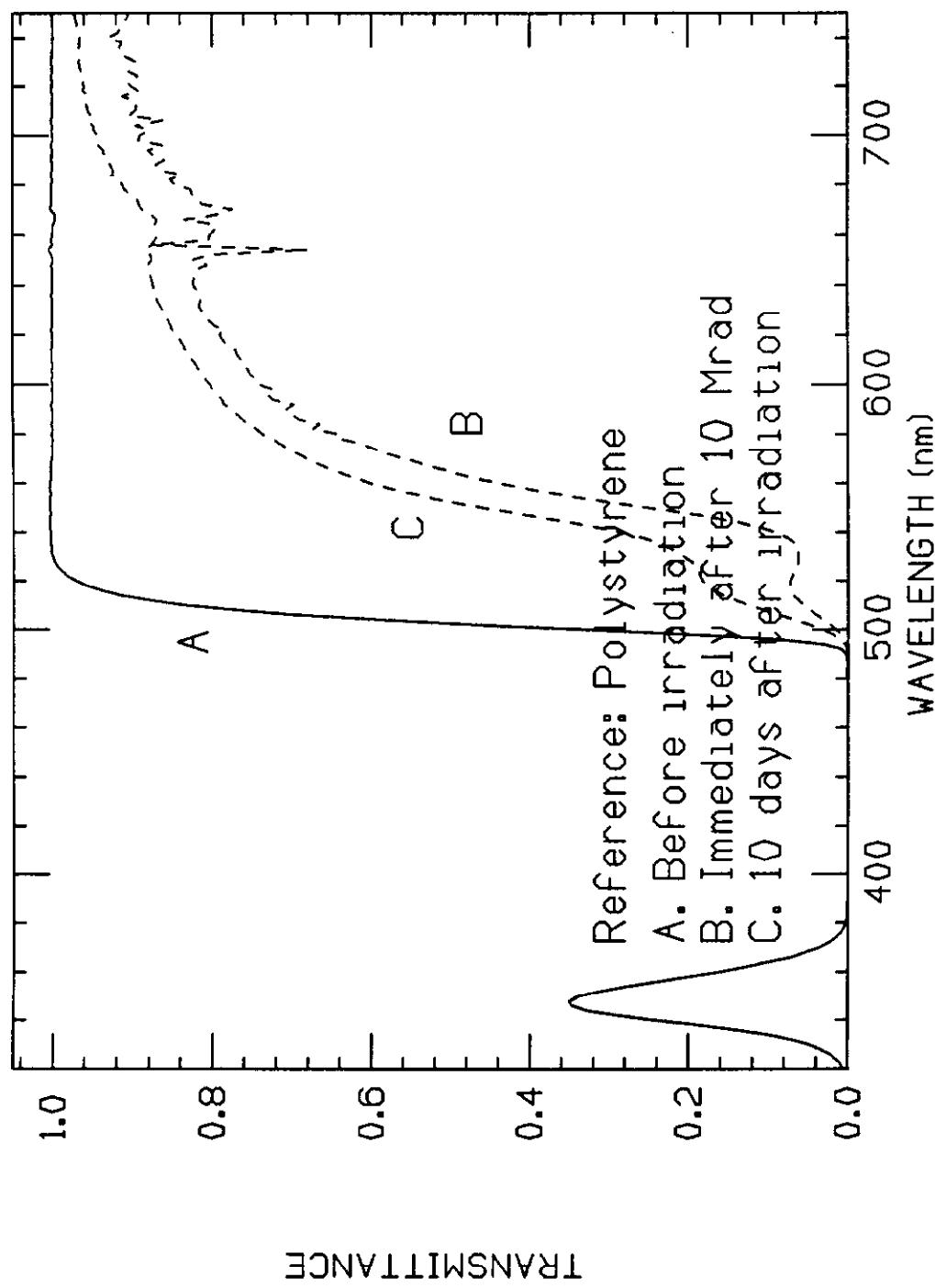
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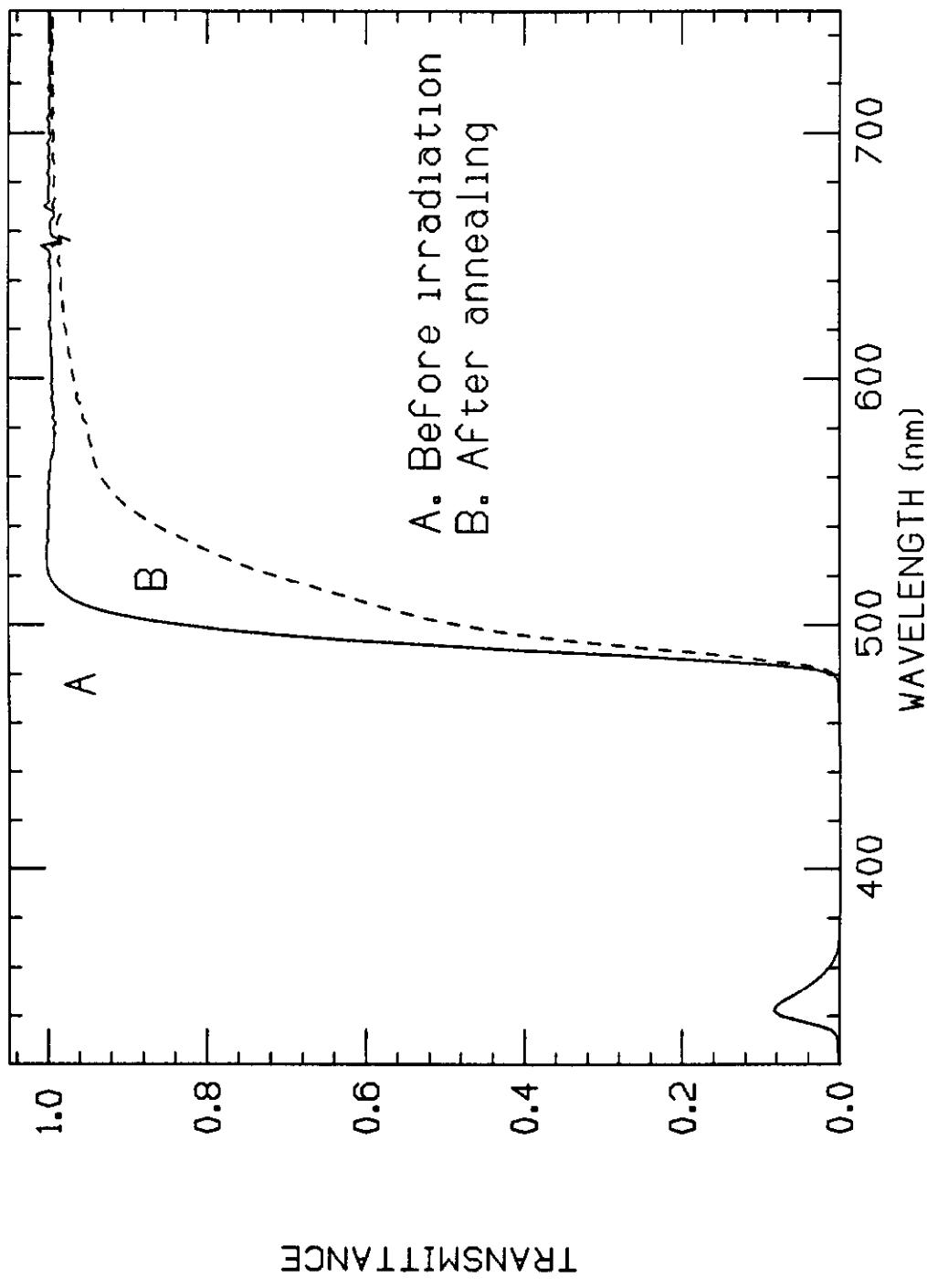
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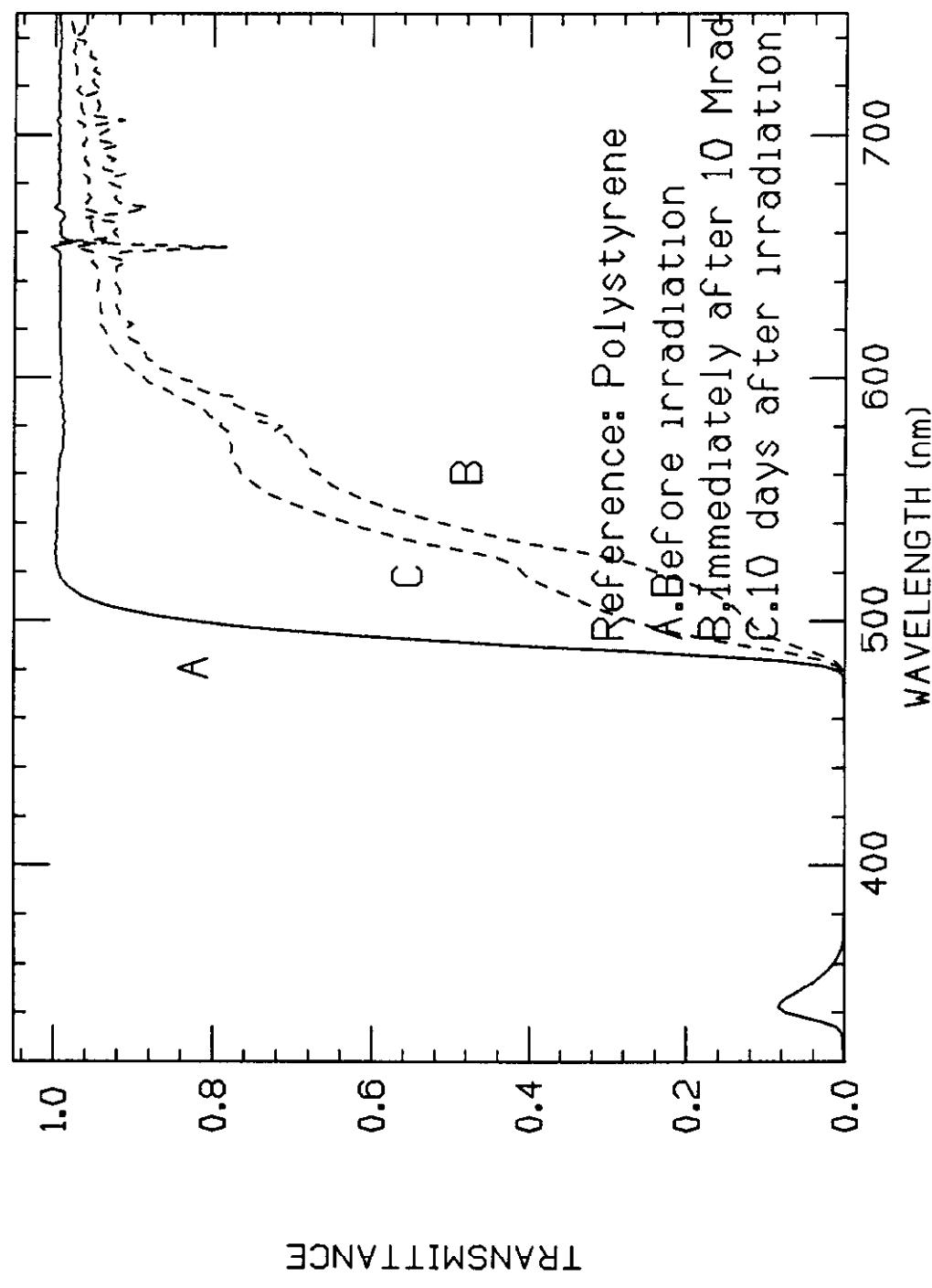
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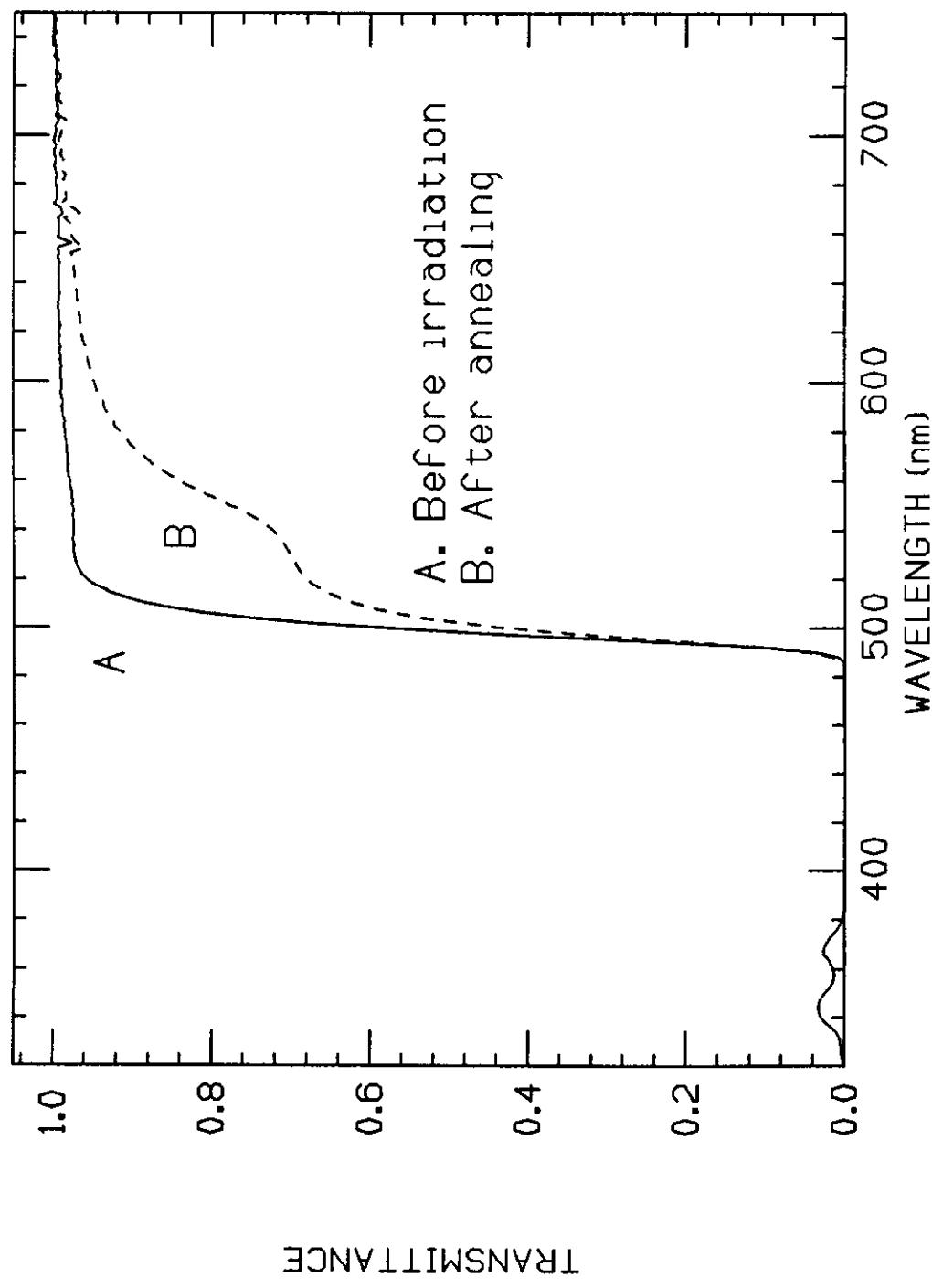
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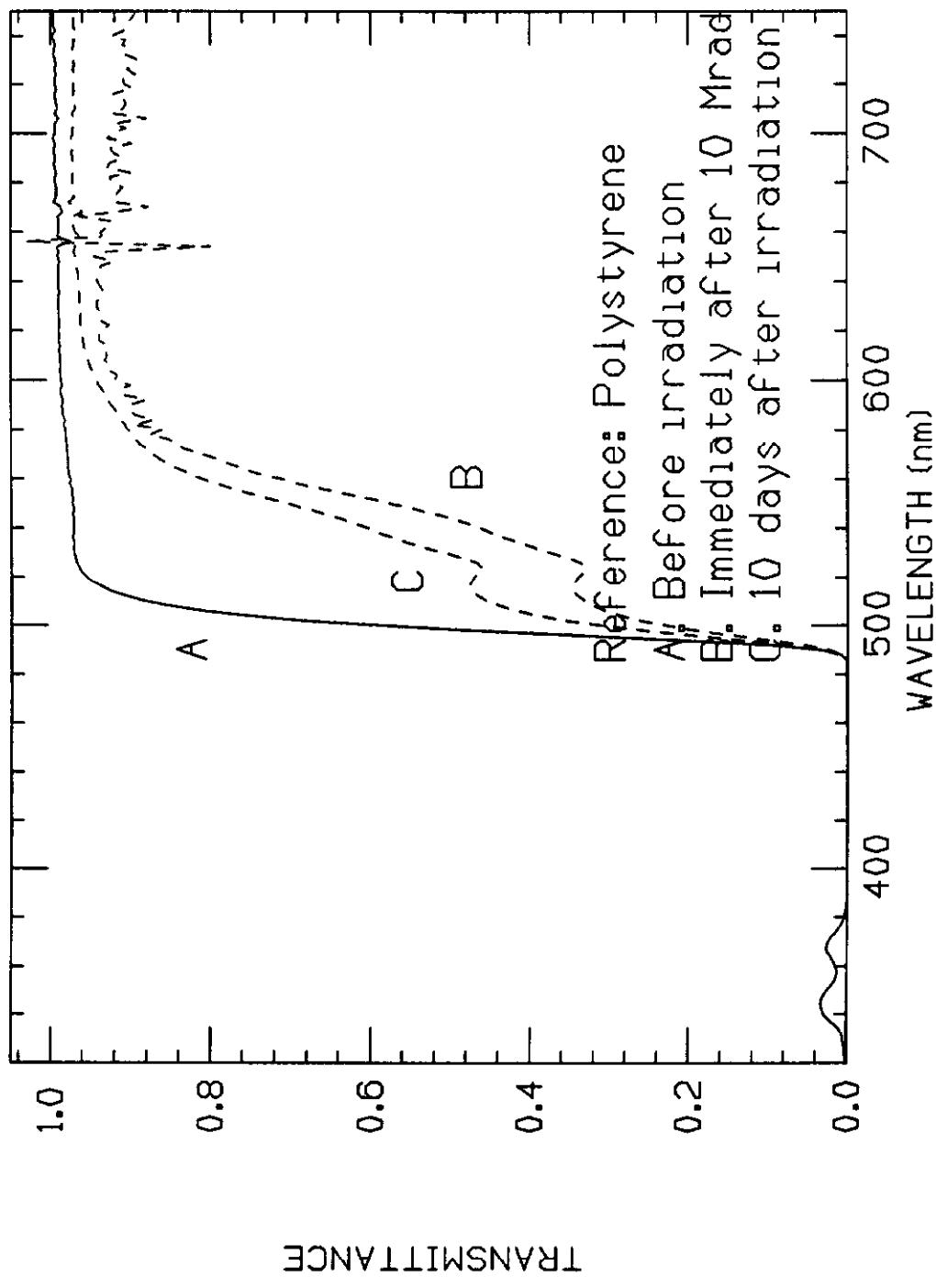
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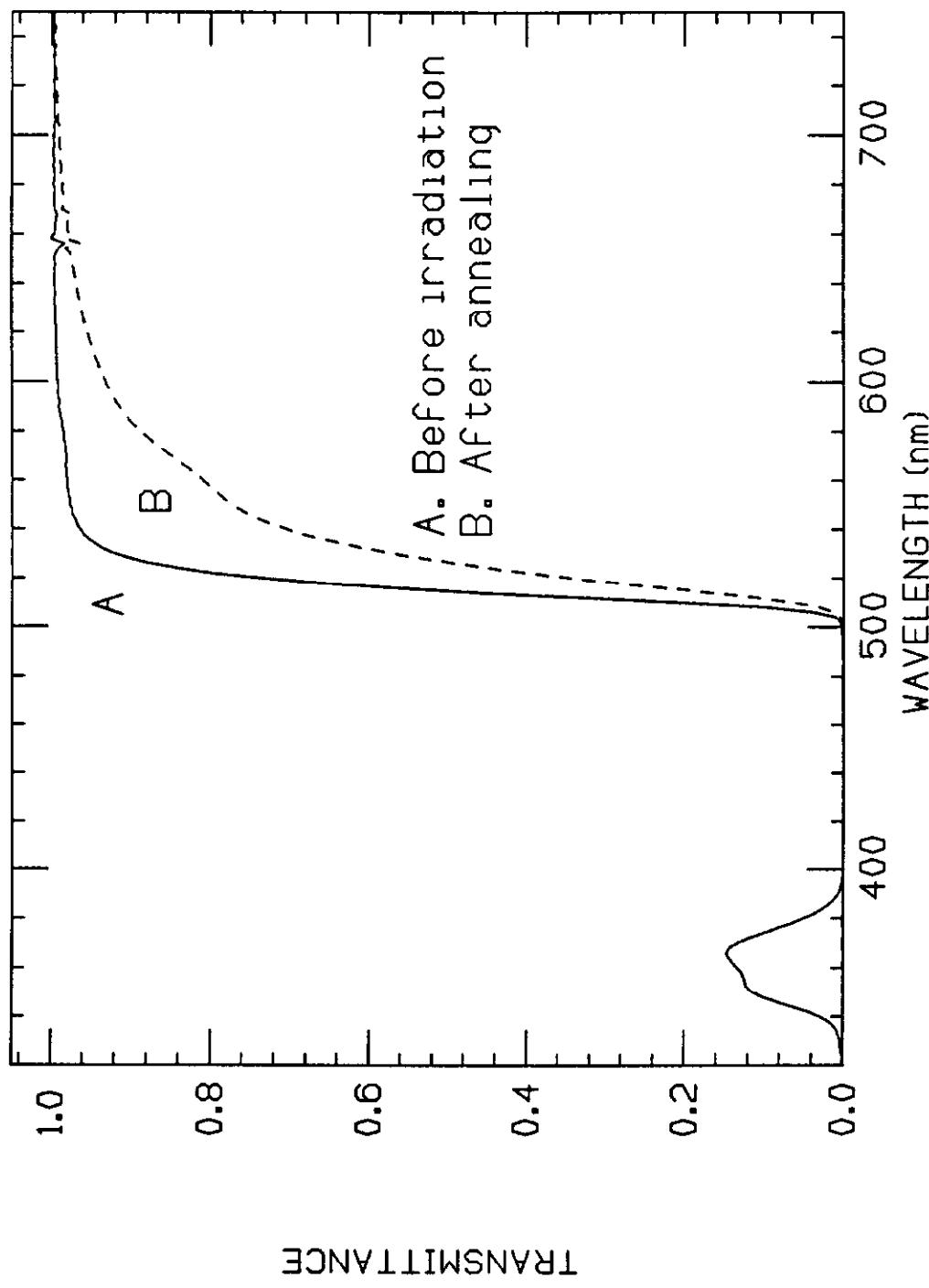
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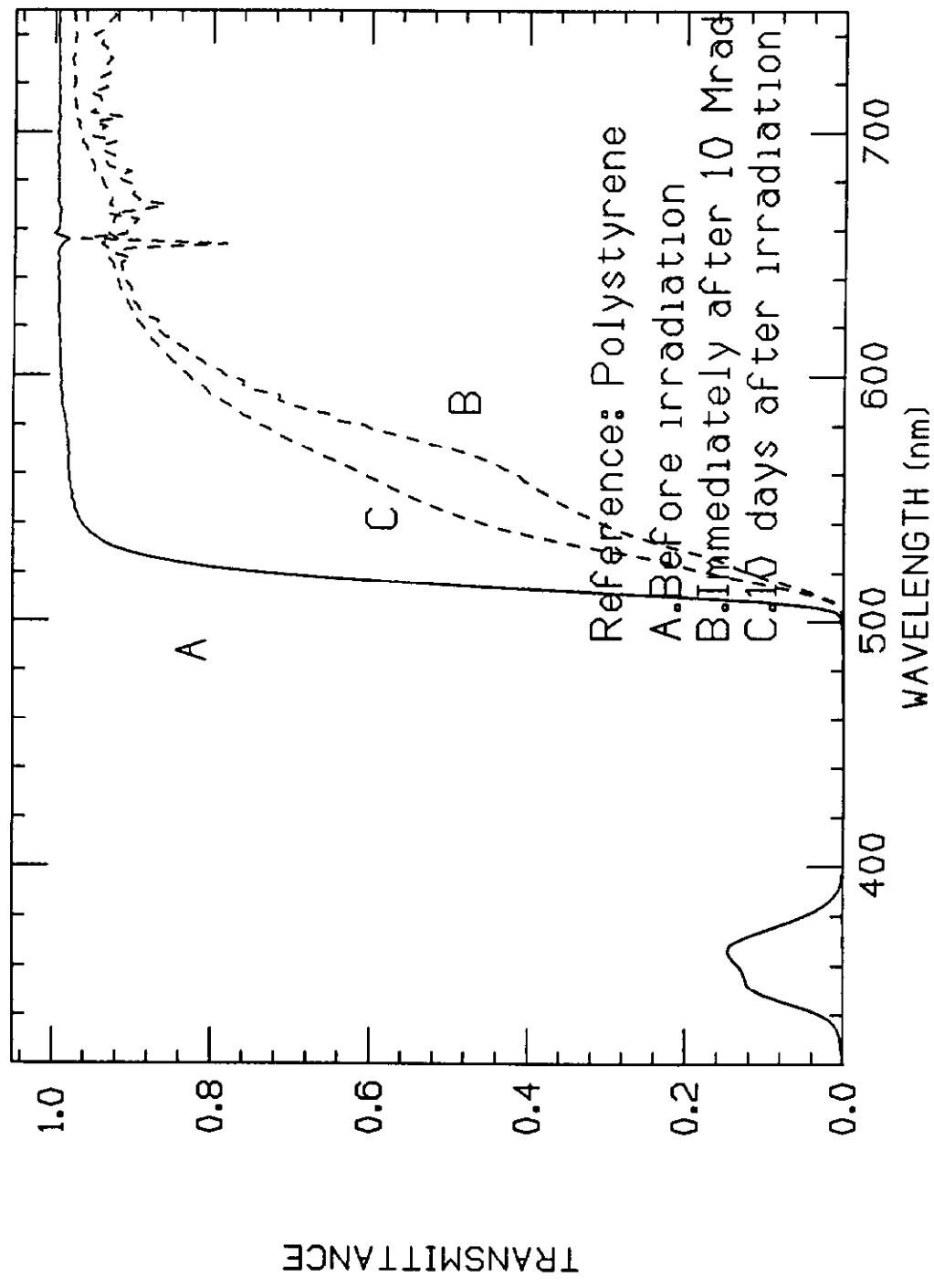
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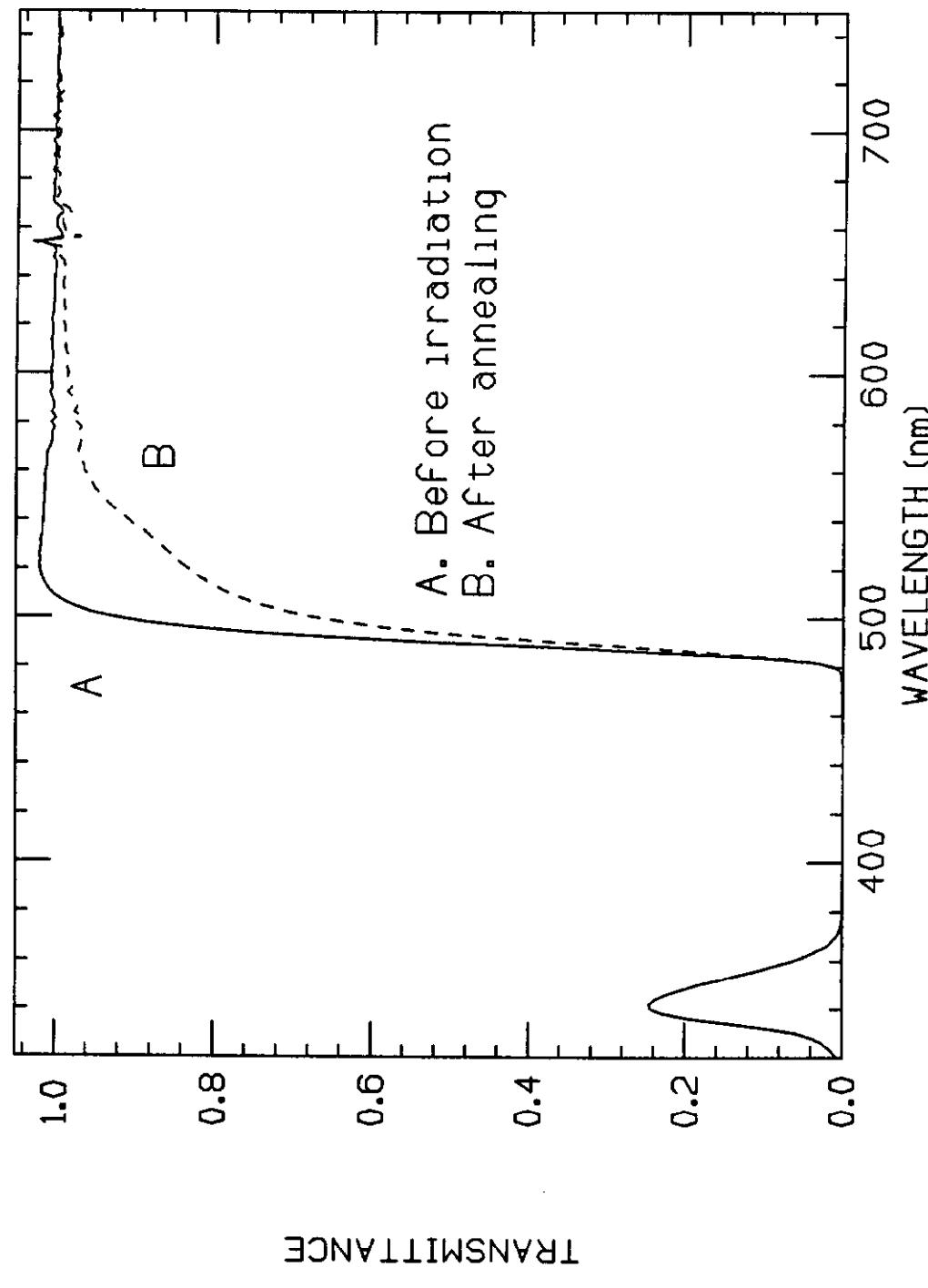
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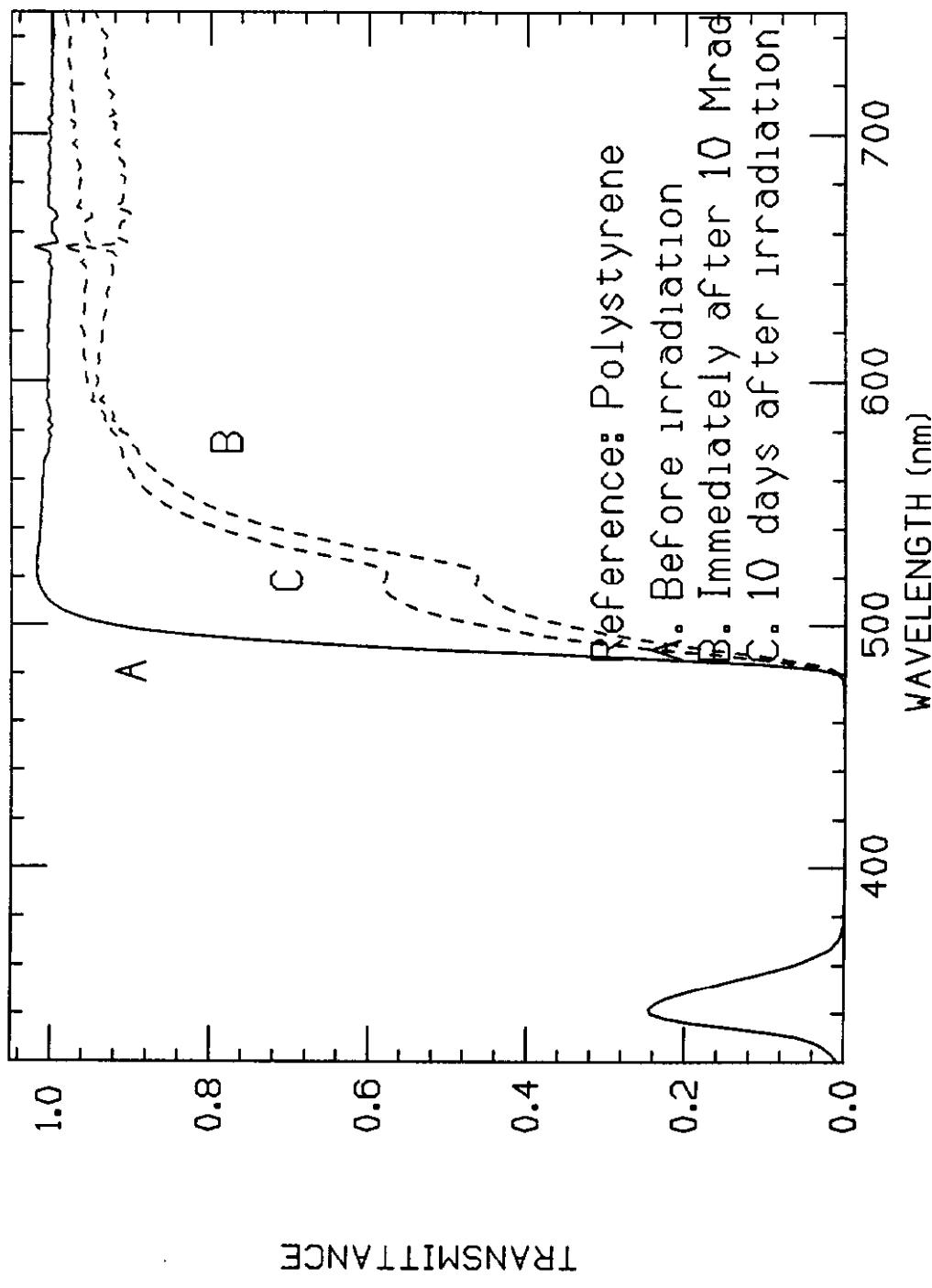
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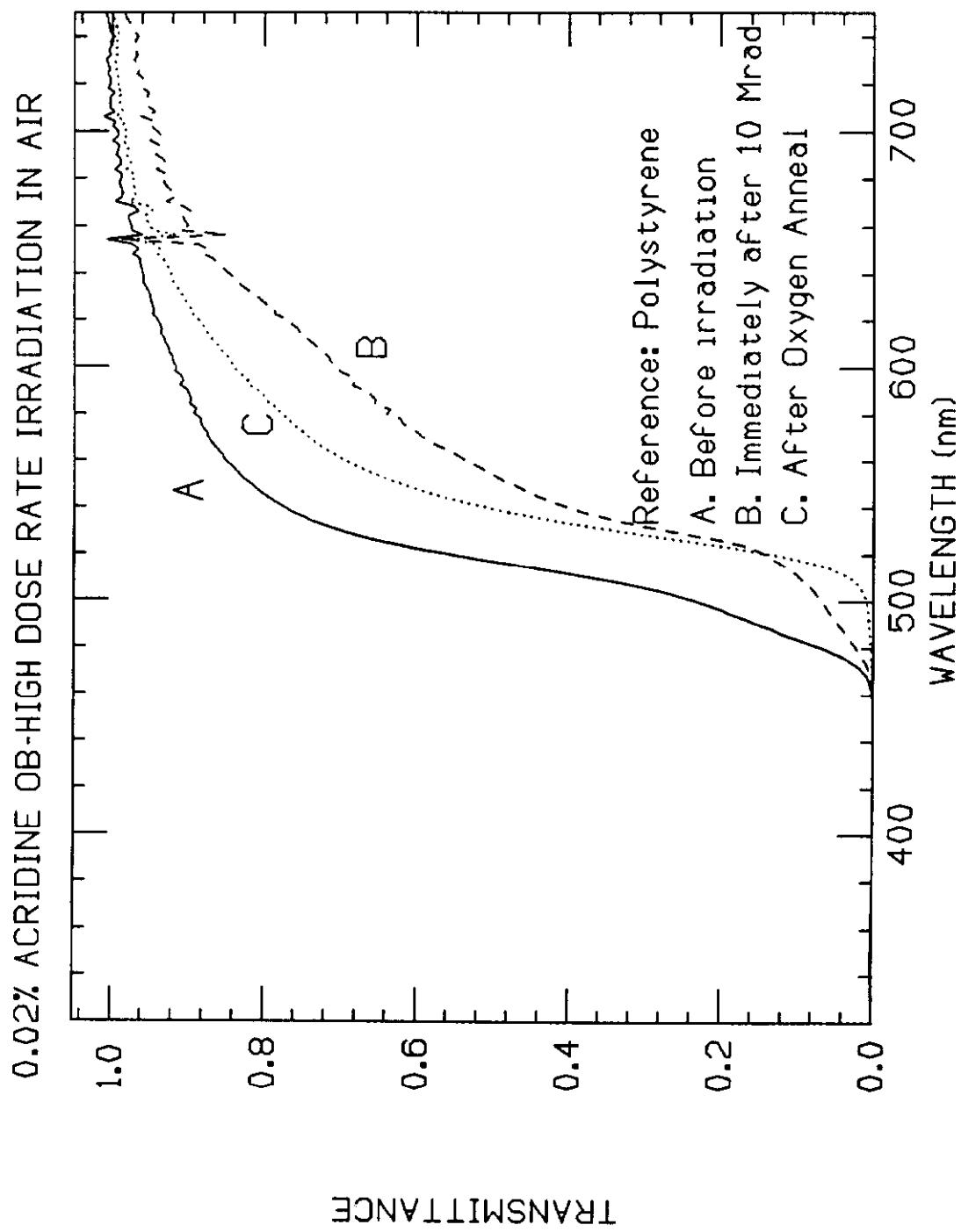
0.02% LP γ - HIGH DOSE RATE IRRADIATION IN AIR



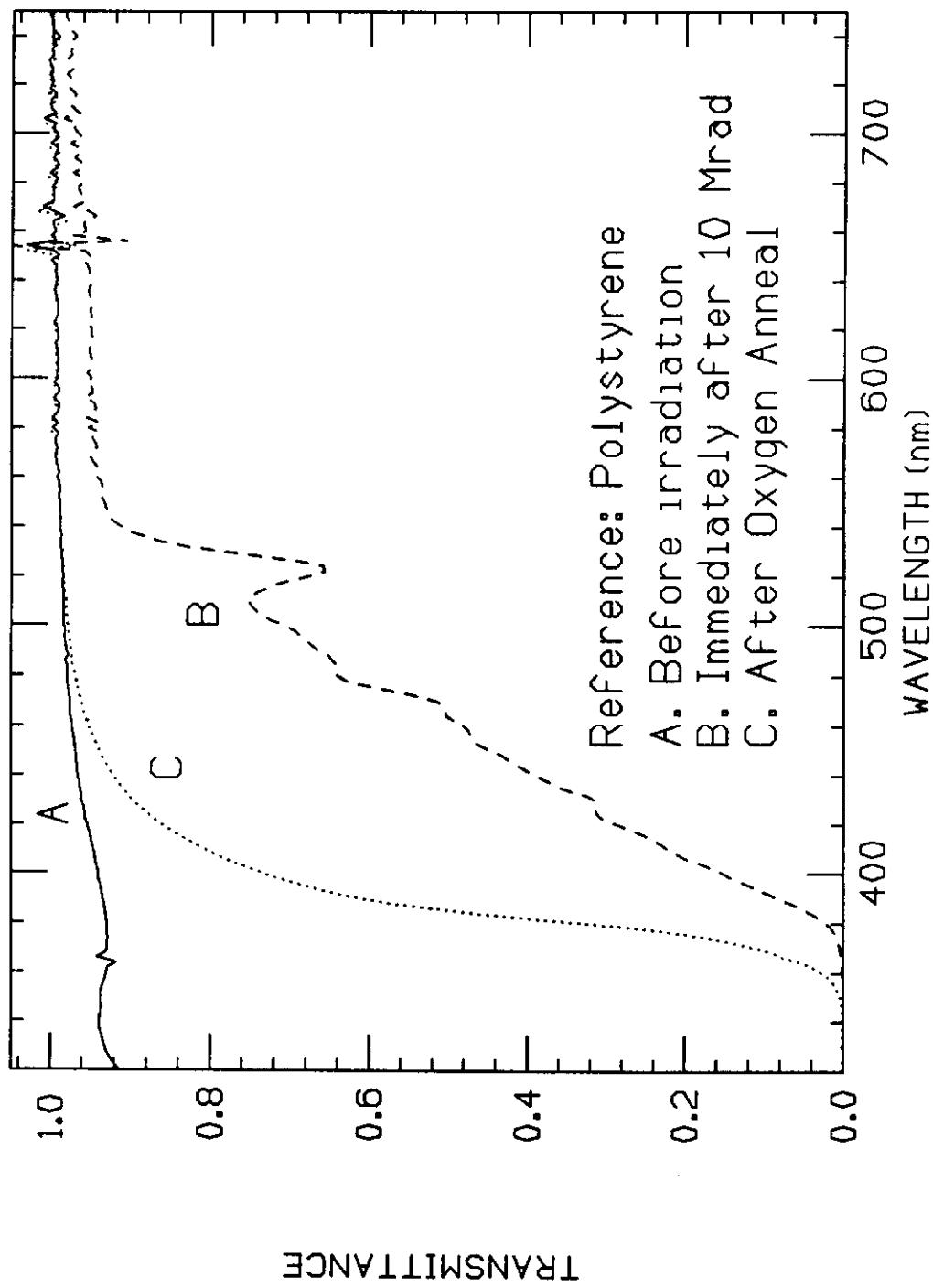
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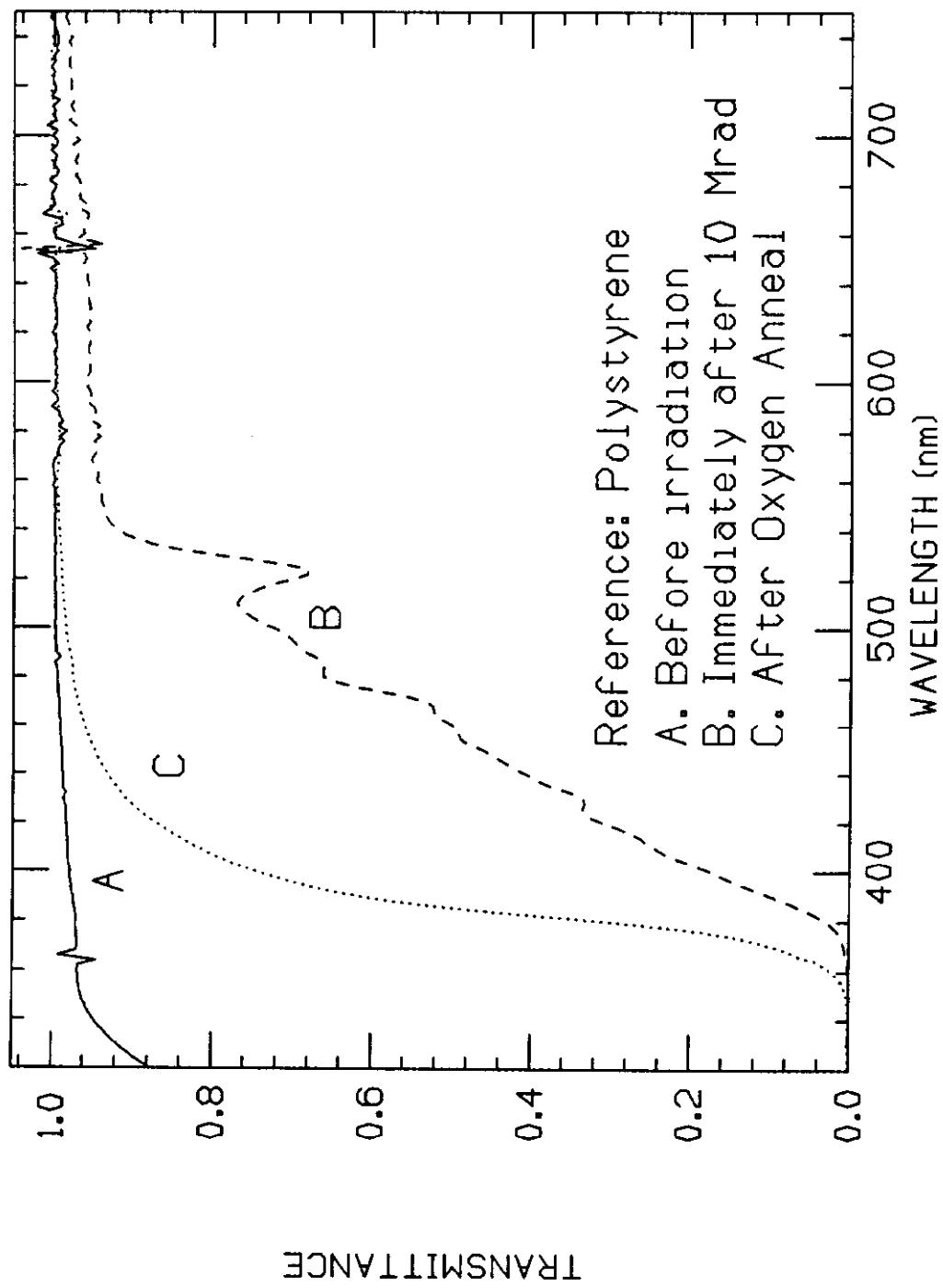
PART II
RADIATION DAMAGE SET #22



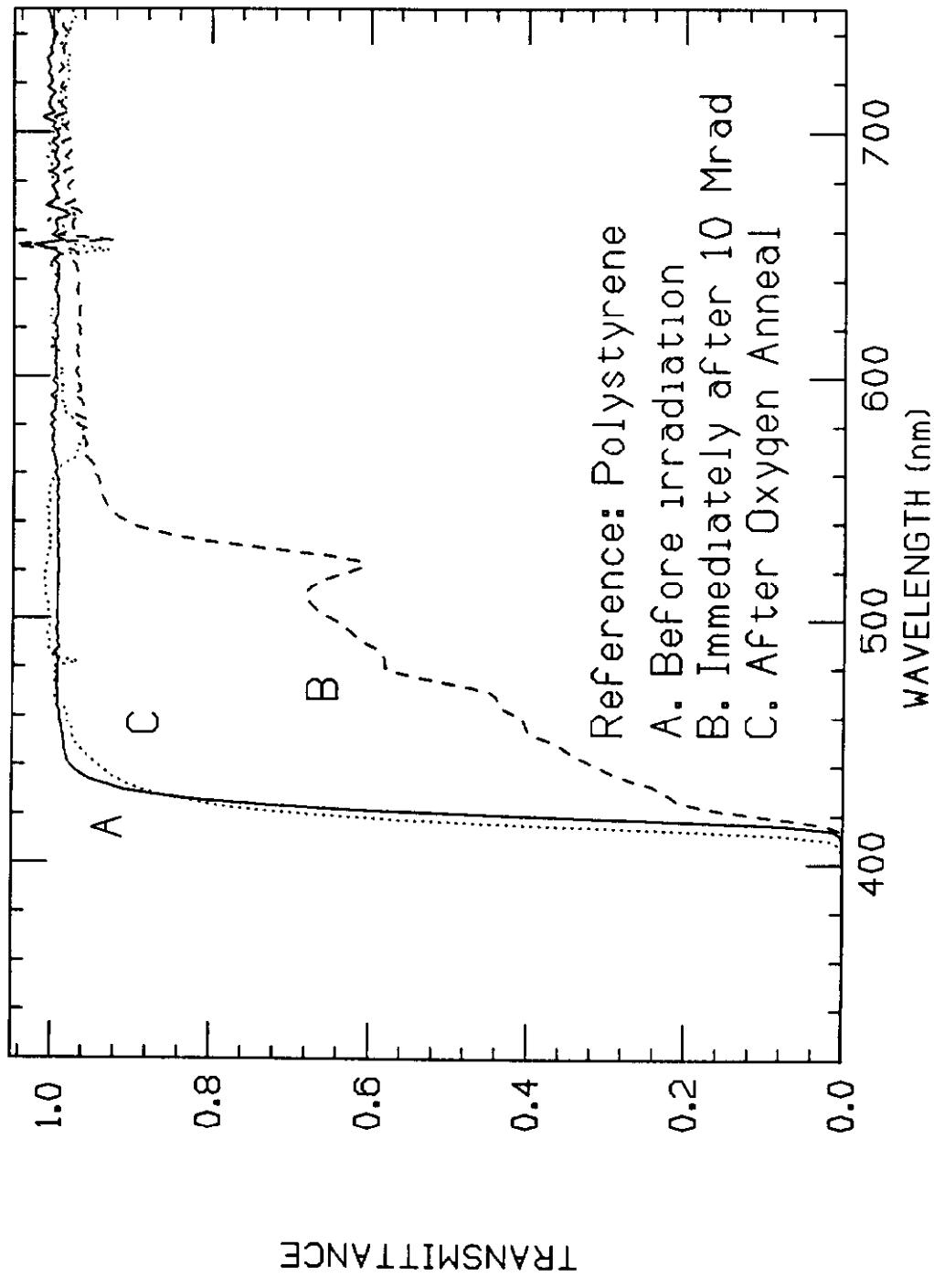
0.02% ACRIDINE γ -HIGH DOSE RATE IRRADIATION IN AIR

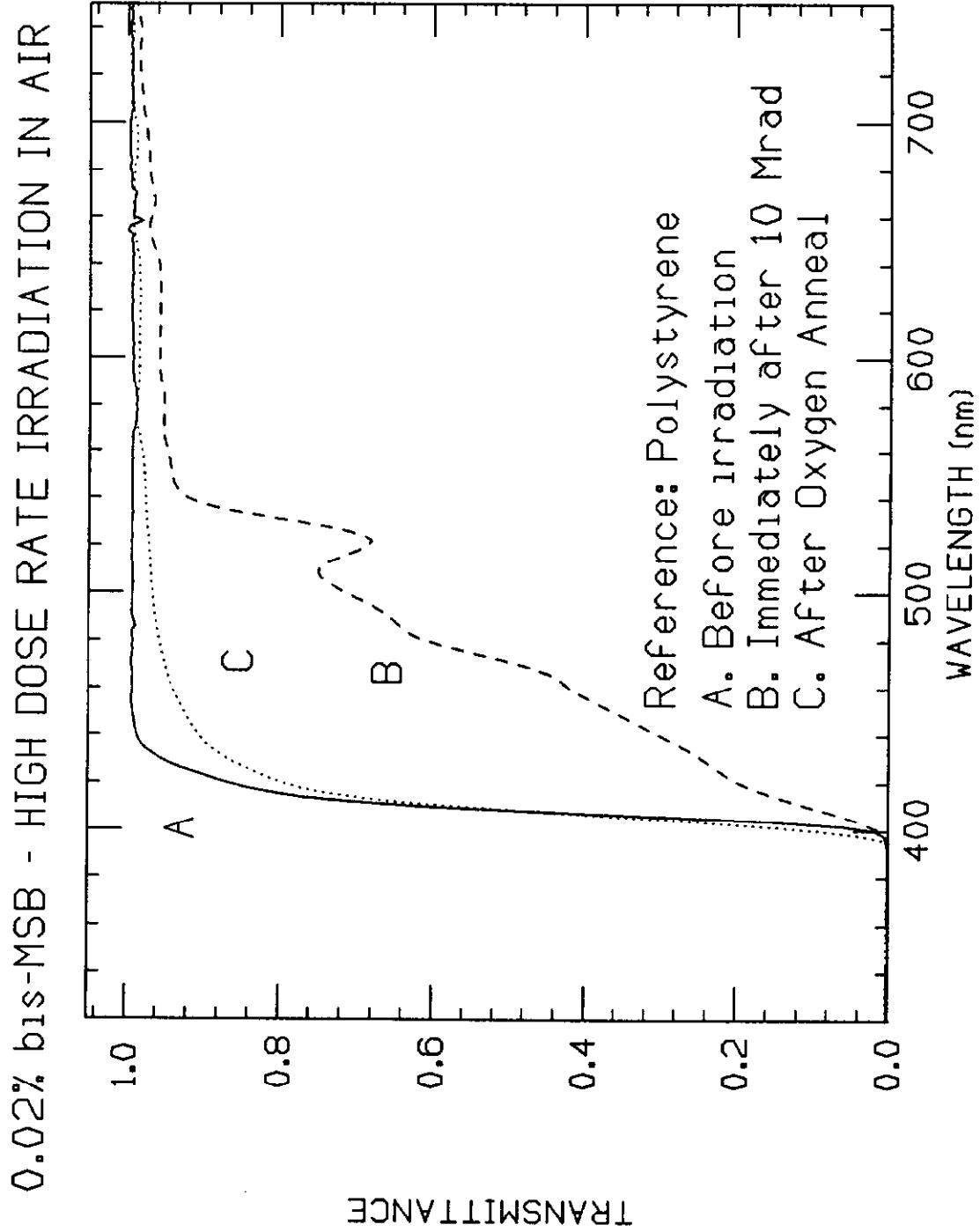


0.02% ACRIFLAVIN - HIGH DOSE RATE IRRADIATION IN AIR

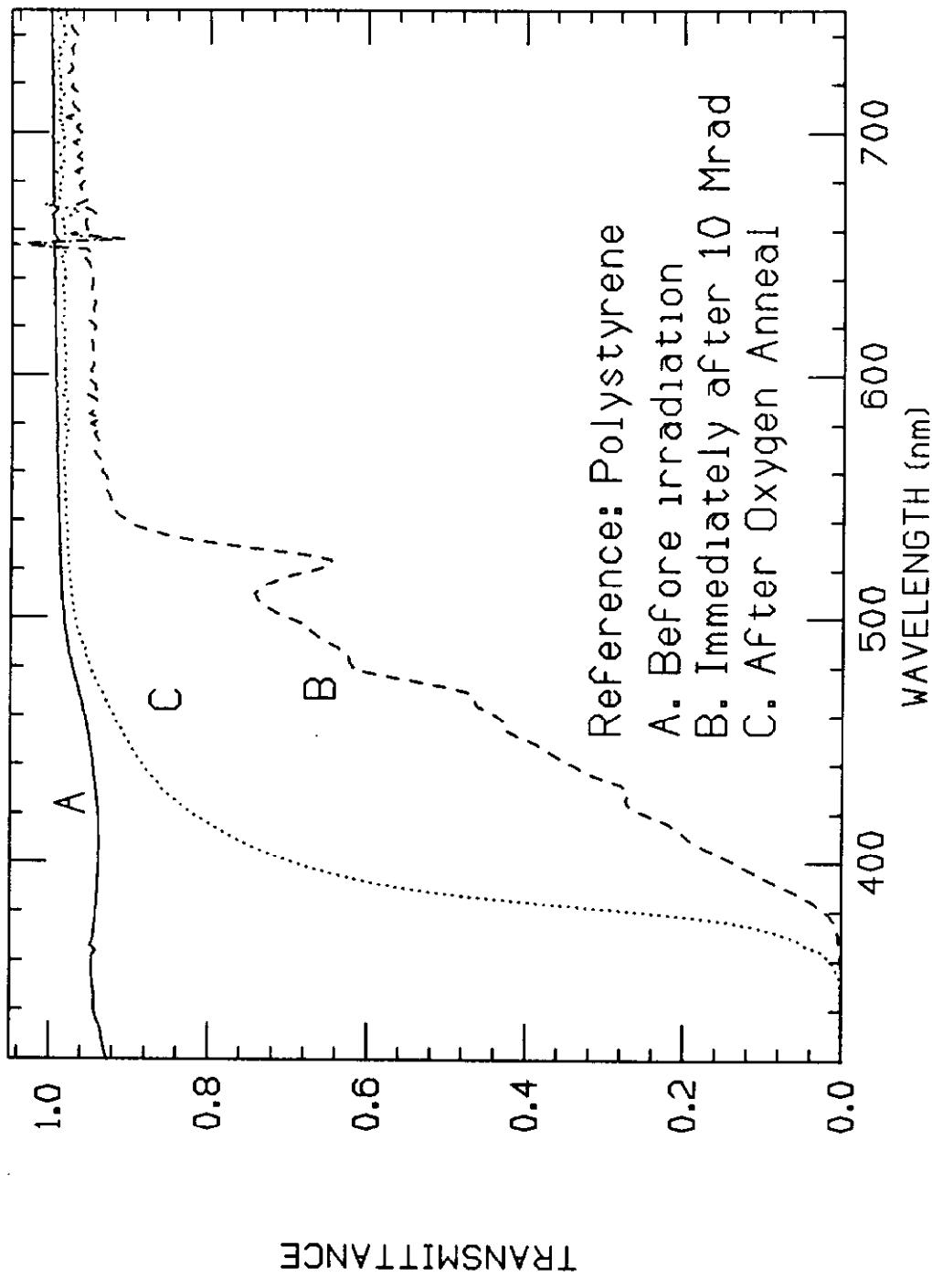


0.02% BBOT - HIGH DOSE RATE IRRADIATION IN AIR

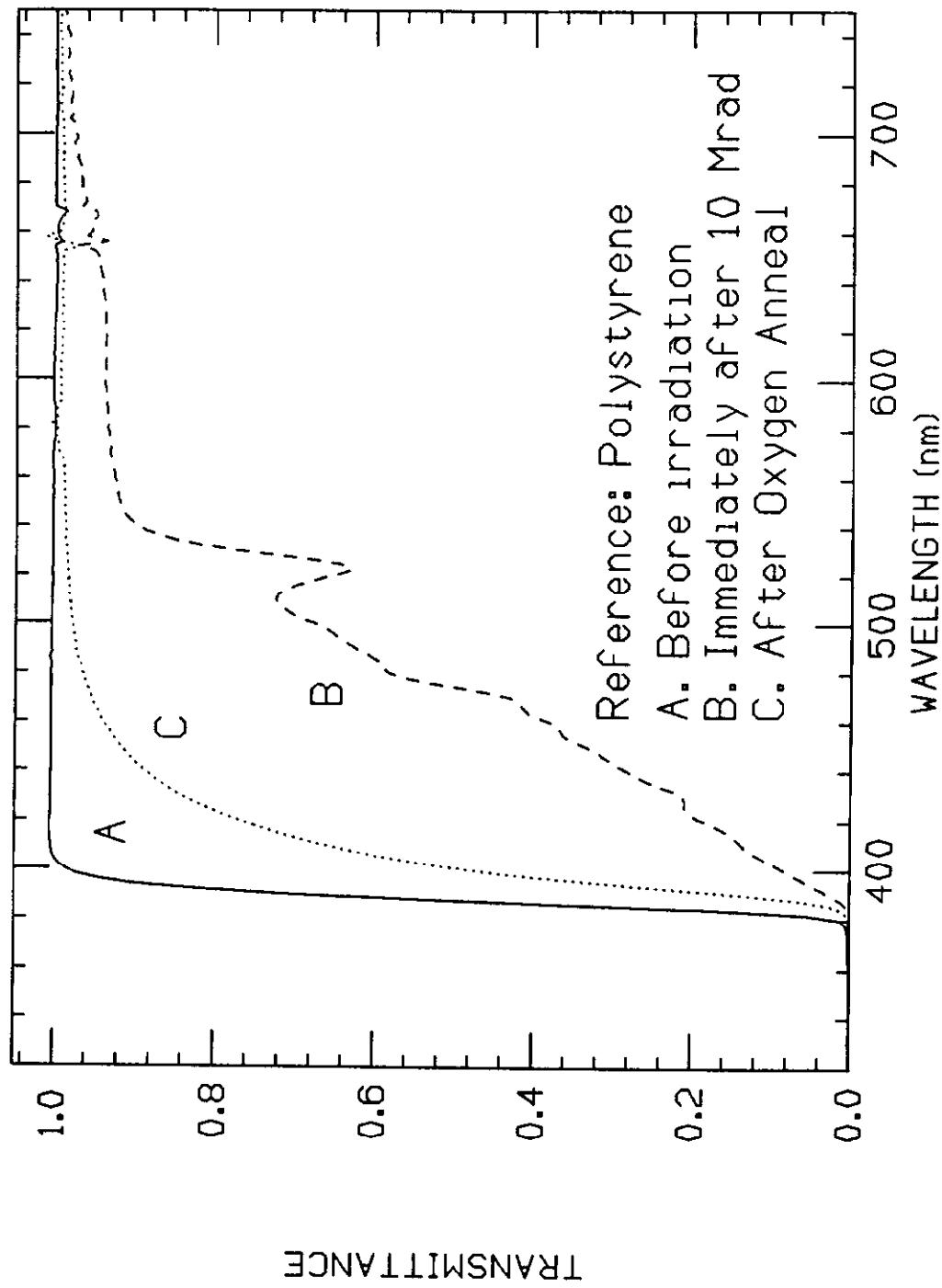




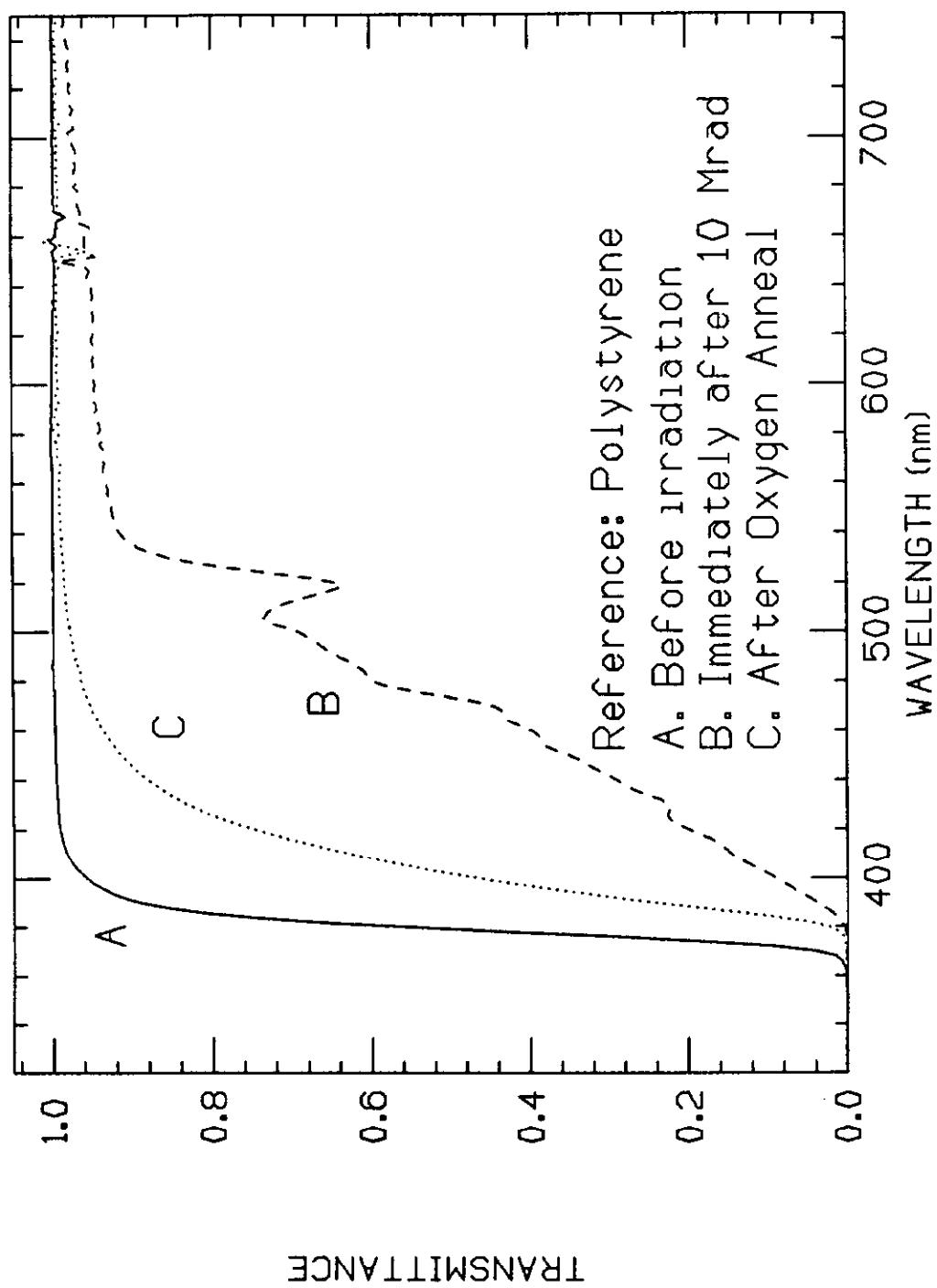
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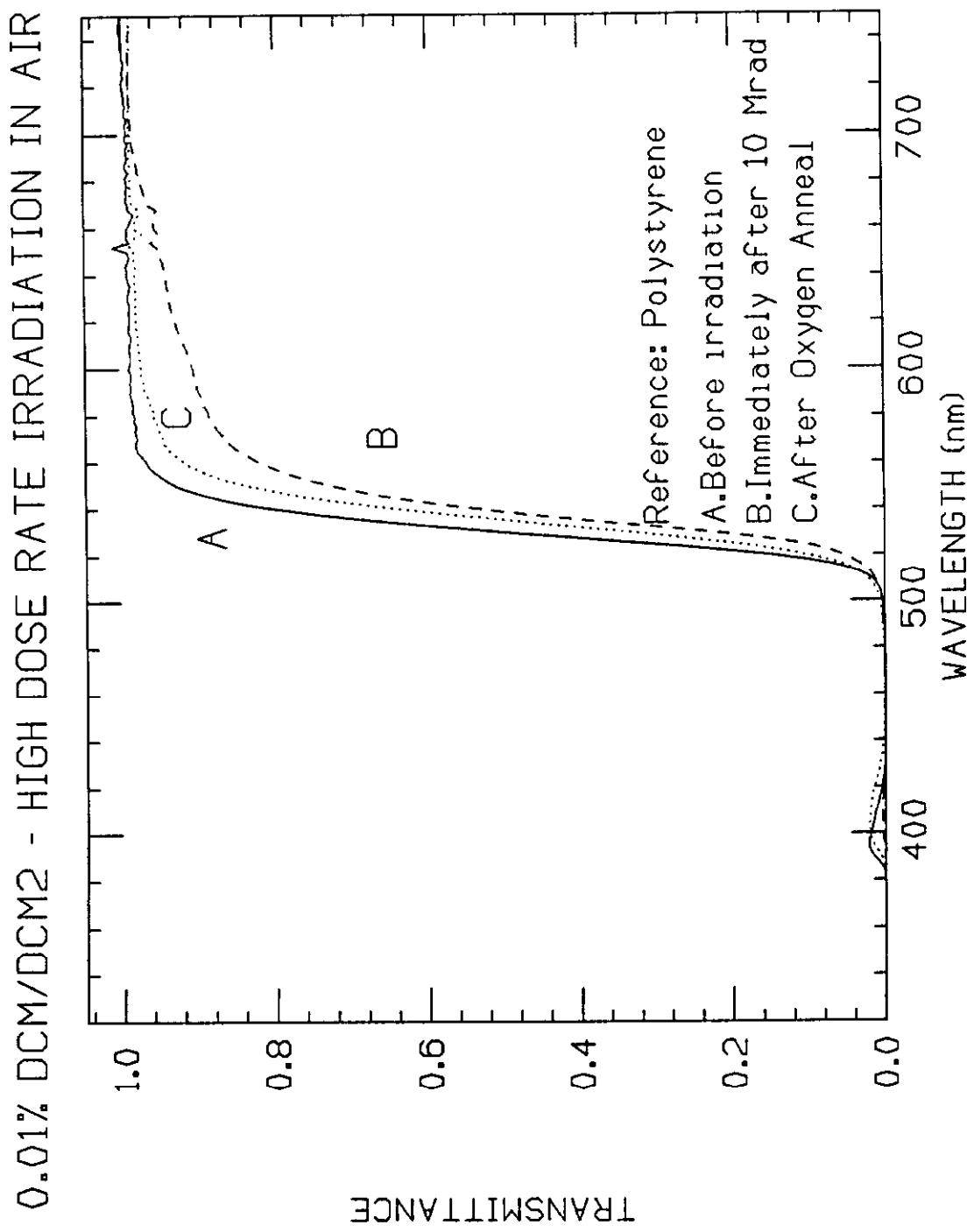


0.02% CARBOSTYRYL 3 -HIGH DOSE RATE IRRADIATION IN AIR

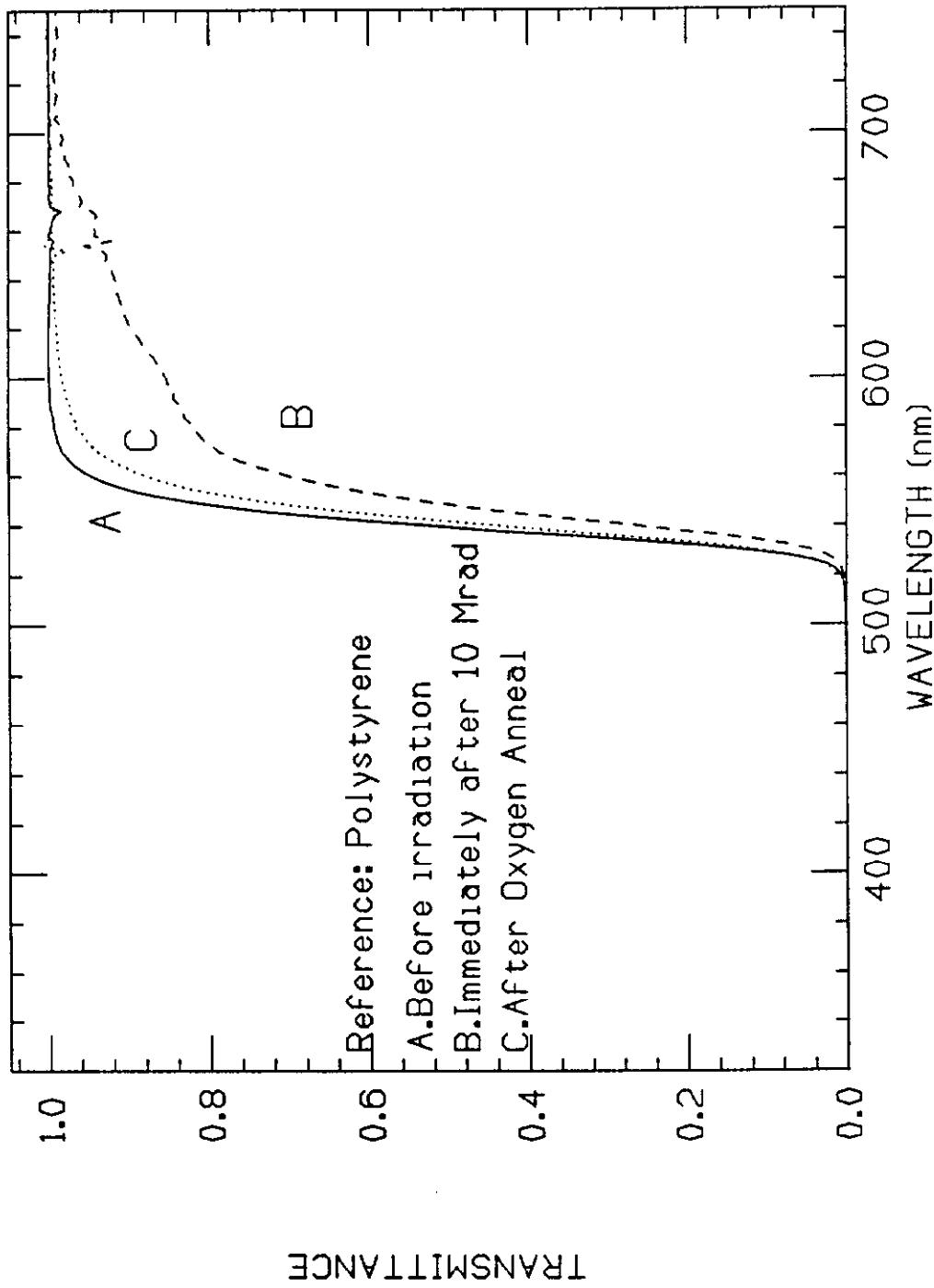


0.02% CBSTY 124 - HIGH DOSE RATE IRRADIATION IN AIR

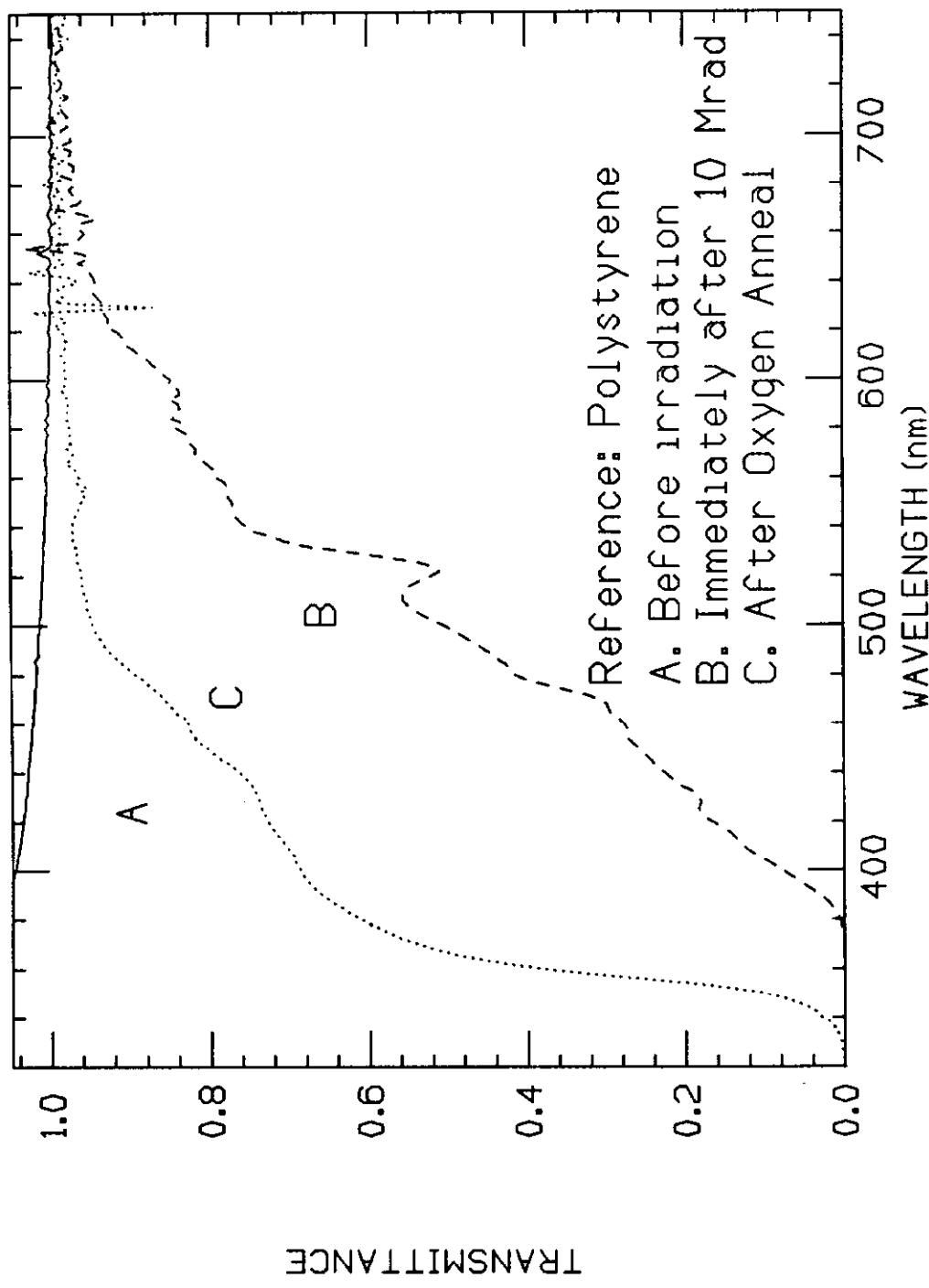




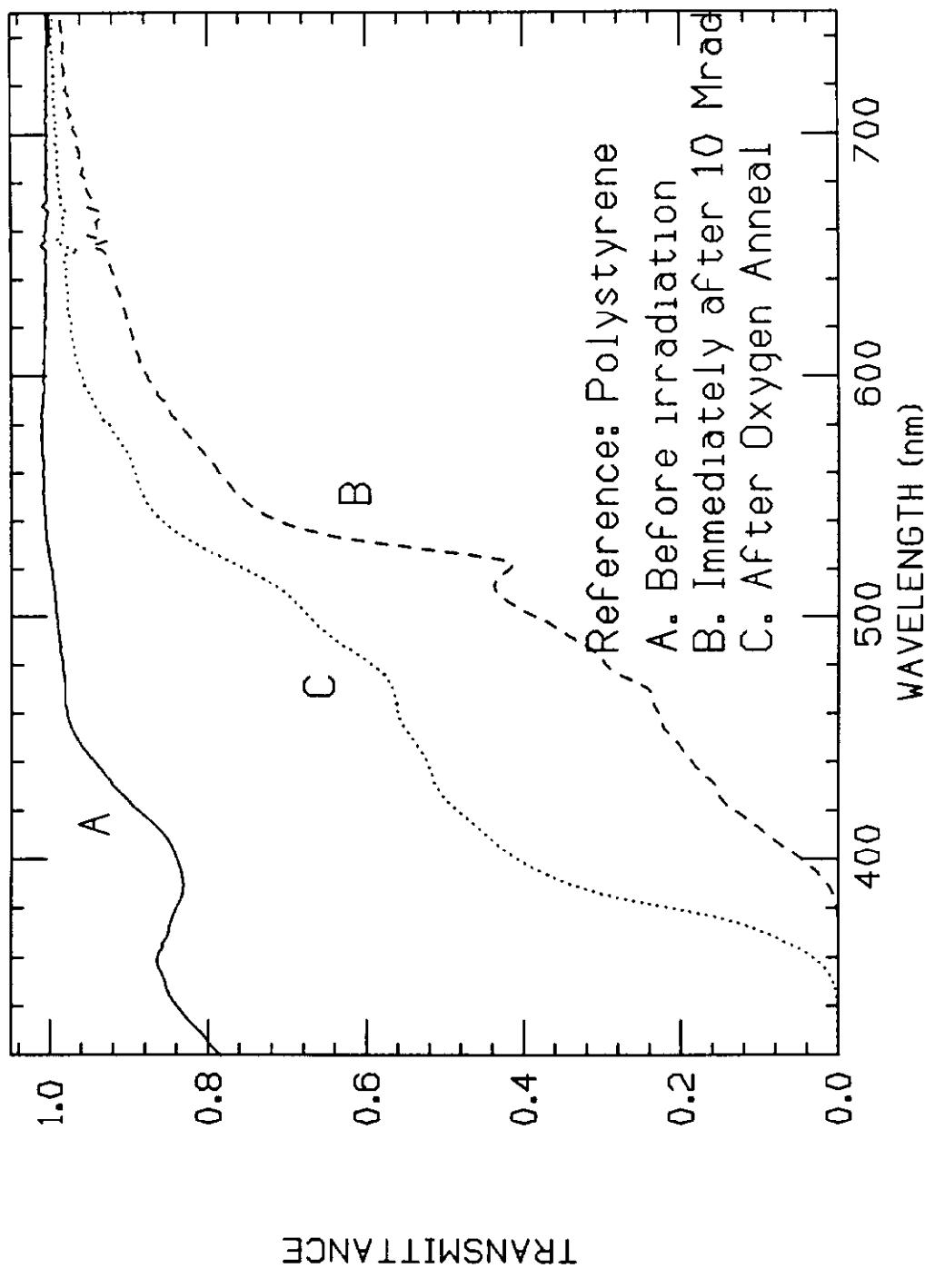
0.02% DCM/DCM2 - HIGH DOSE RATE IRRADIATION IN AIR

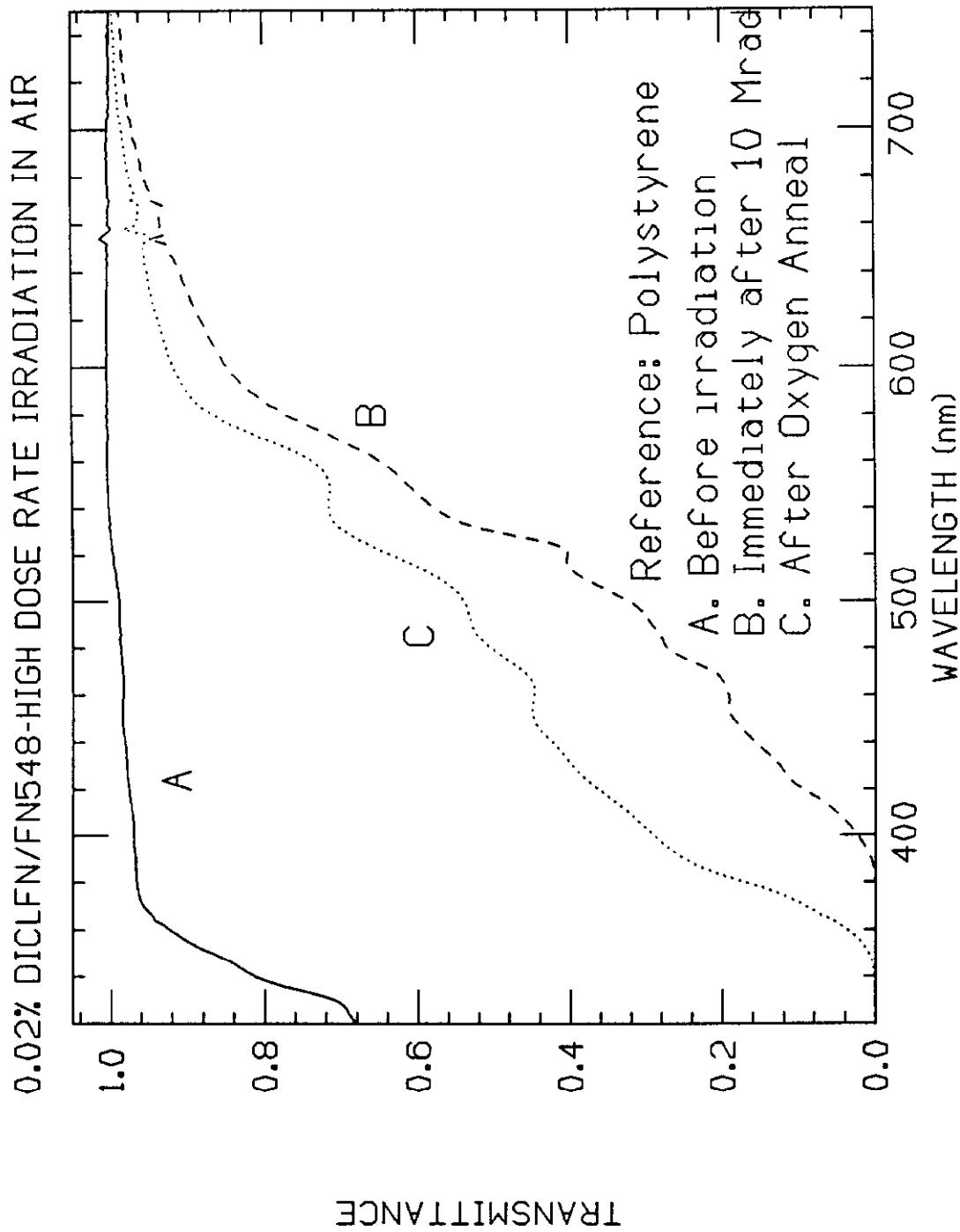


0.02% DIACFN - HIGH DOSE RATE IRRADIATION IN AIR

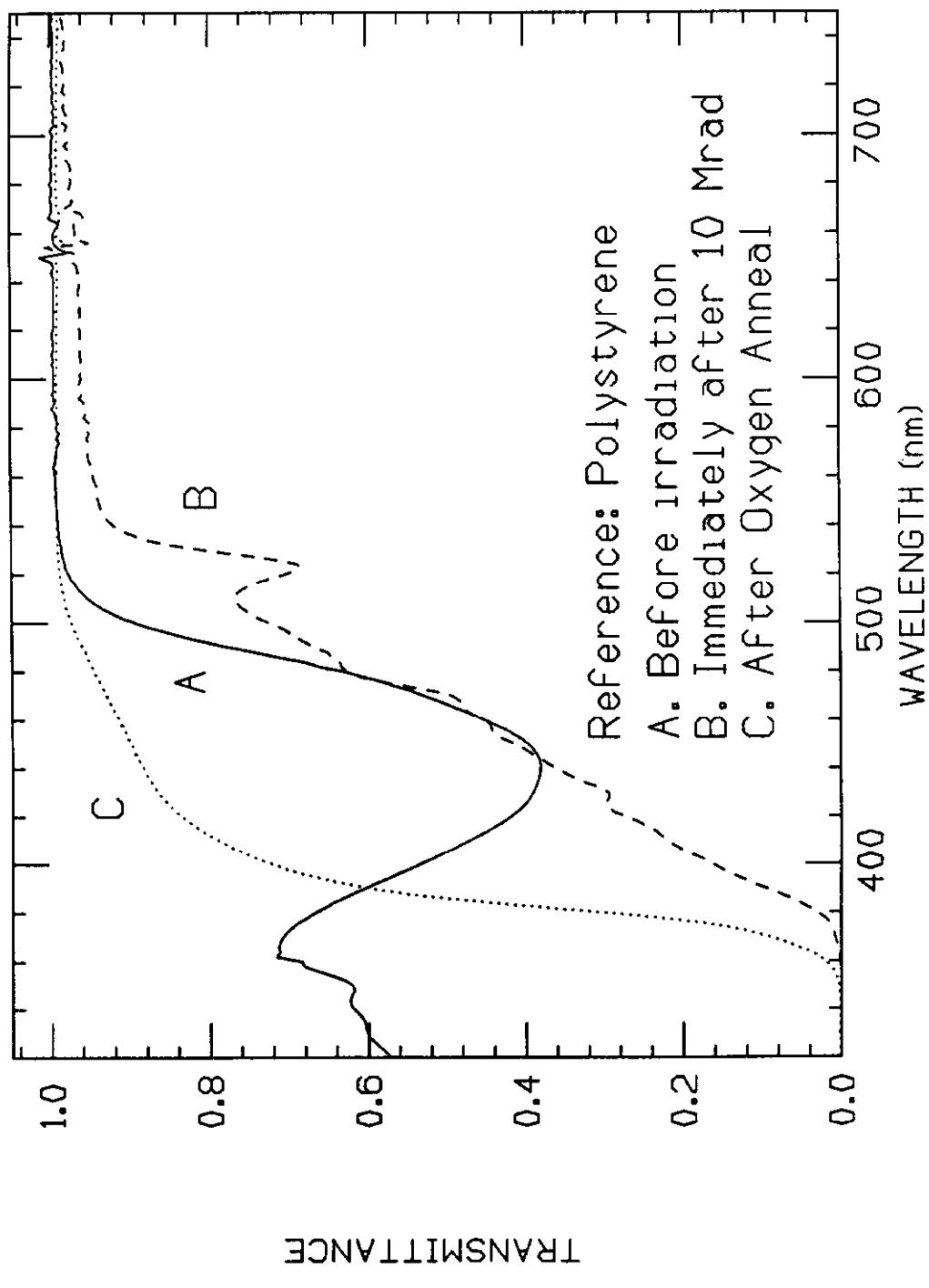


0.02% DIBRN - HIGH DOSE RATE IRRADIATION IN AIR

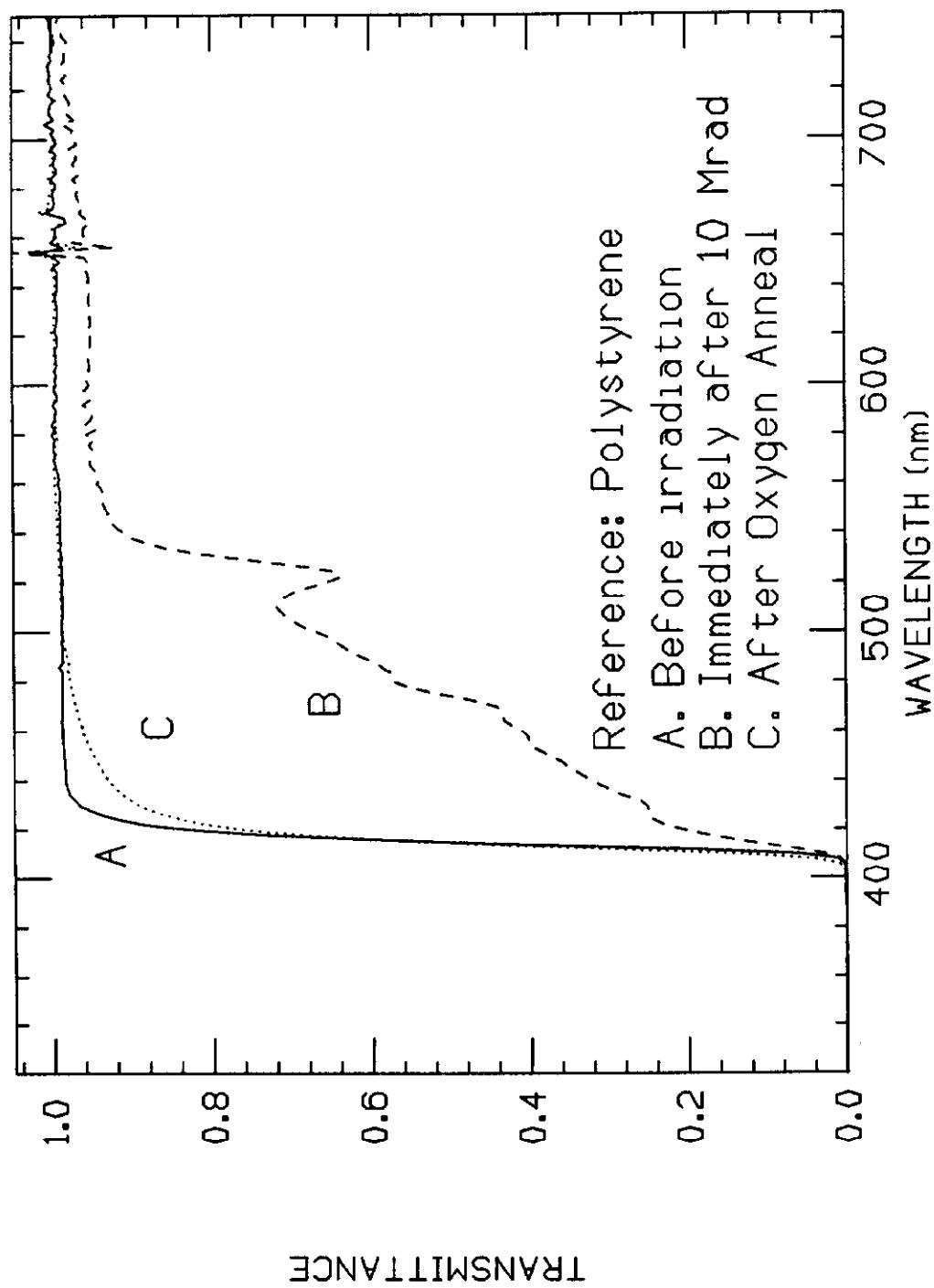




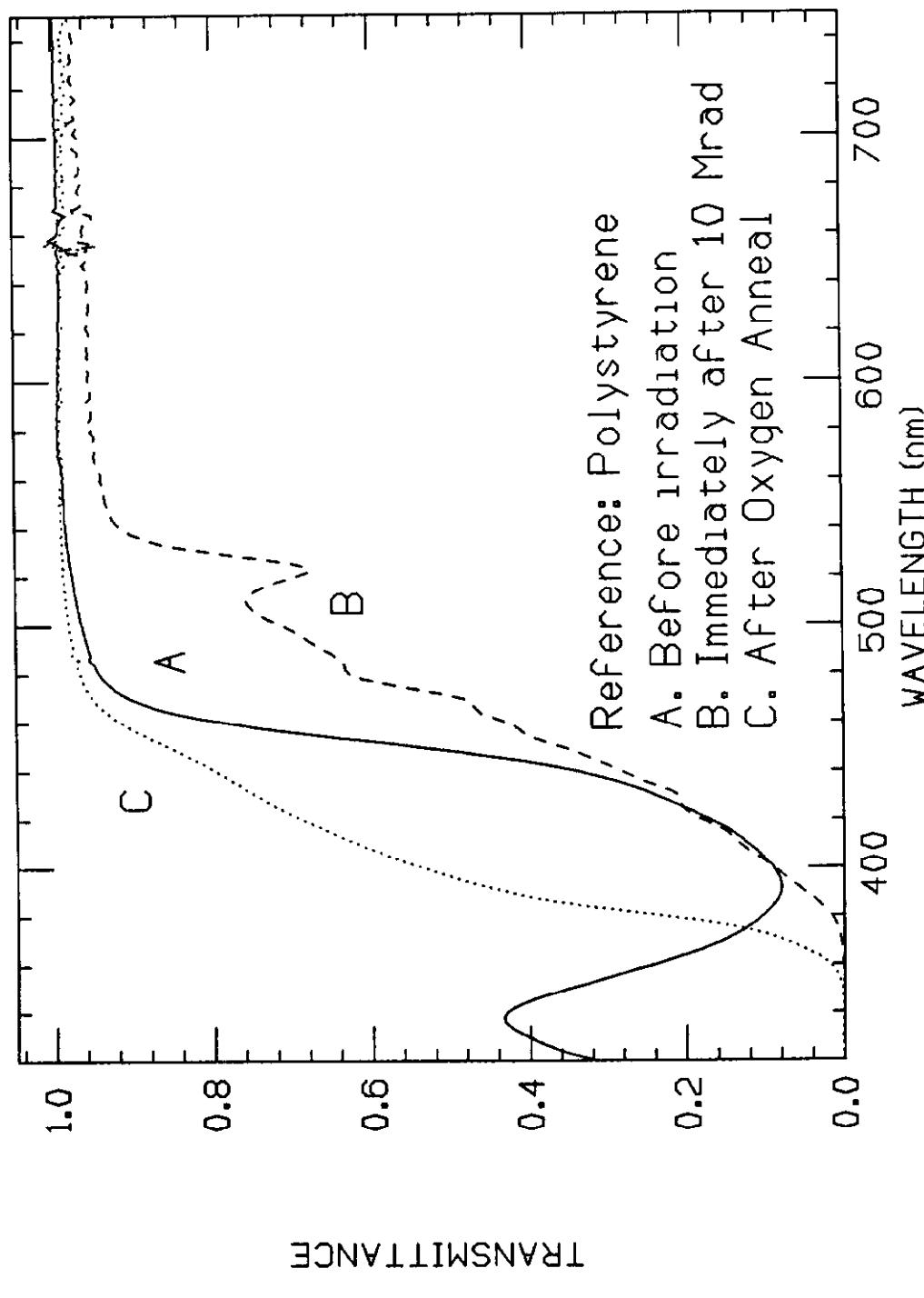
0.02% DMETCI - HIGH DOSE RATE IRRADIATION IN AIR



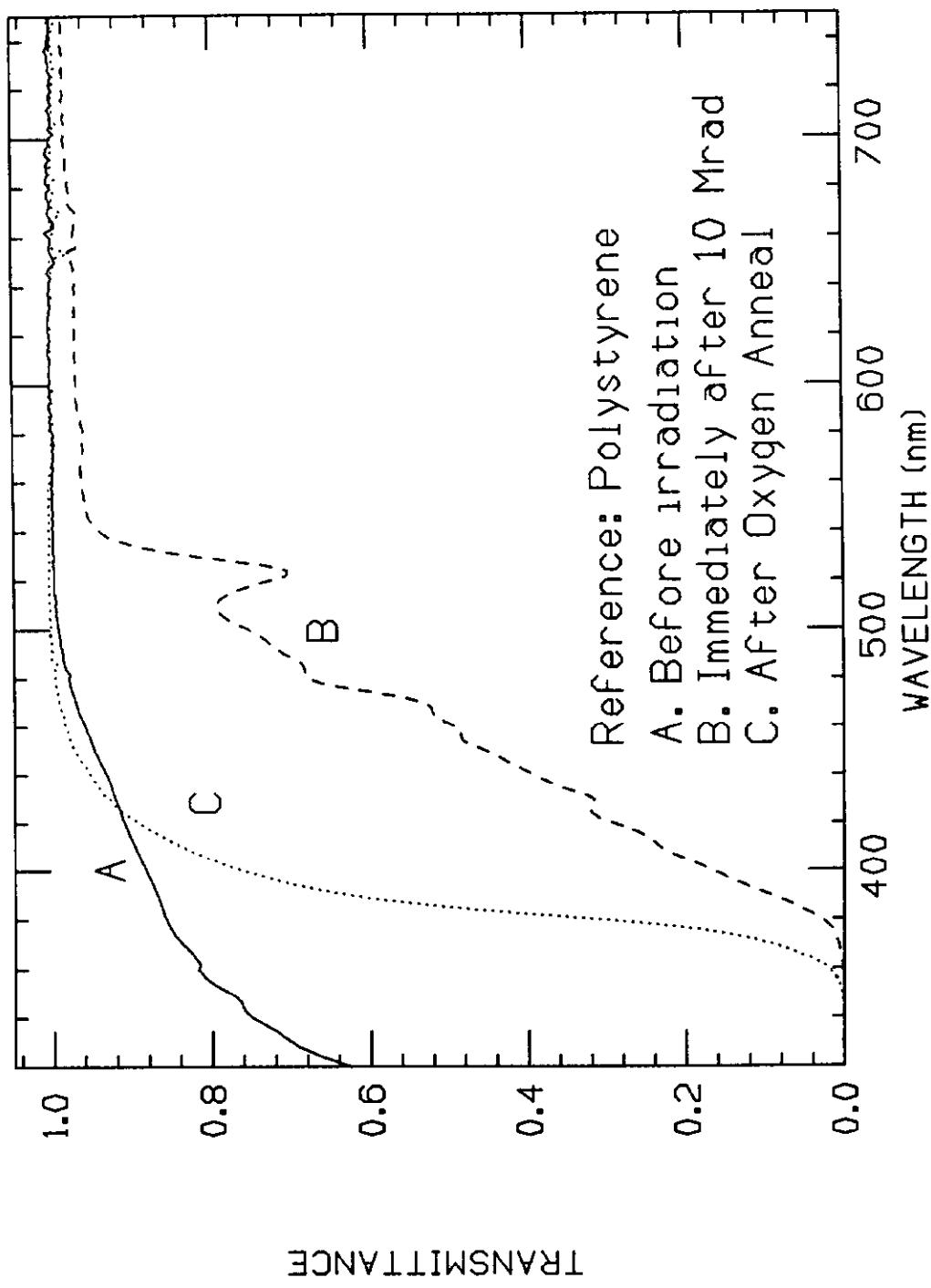
0.02% DMPOPOP - HIGH DOSE RATE IRRADIATION IN AIR

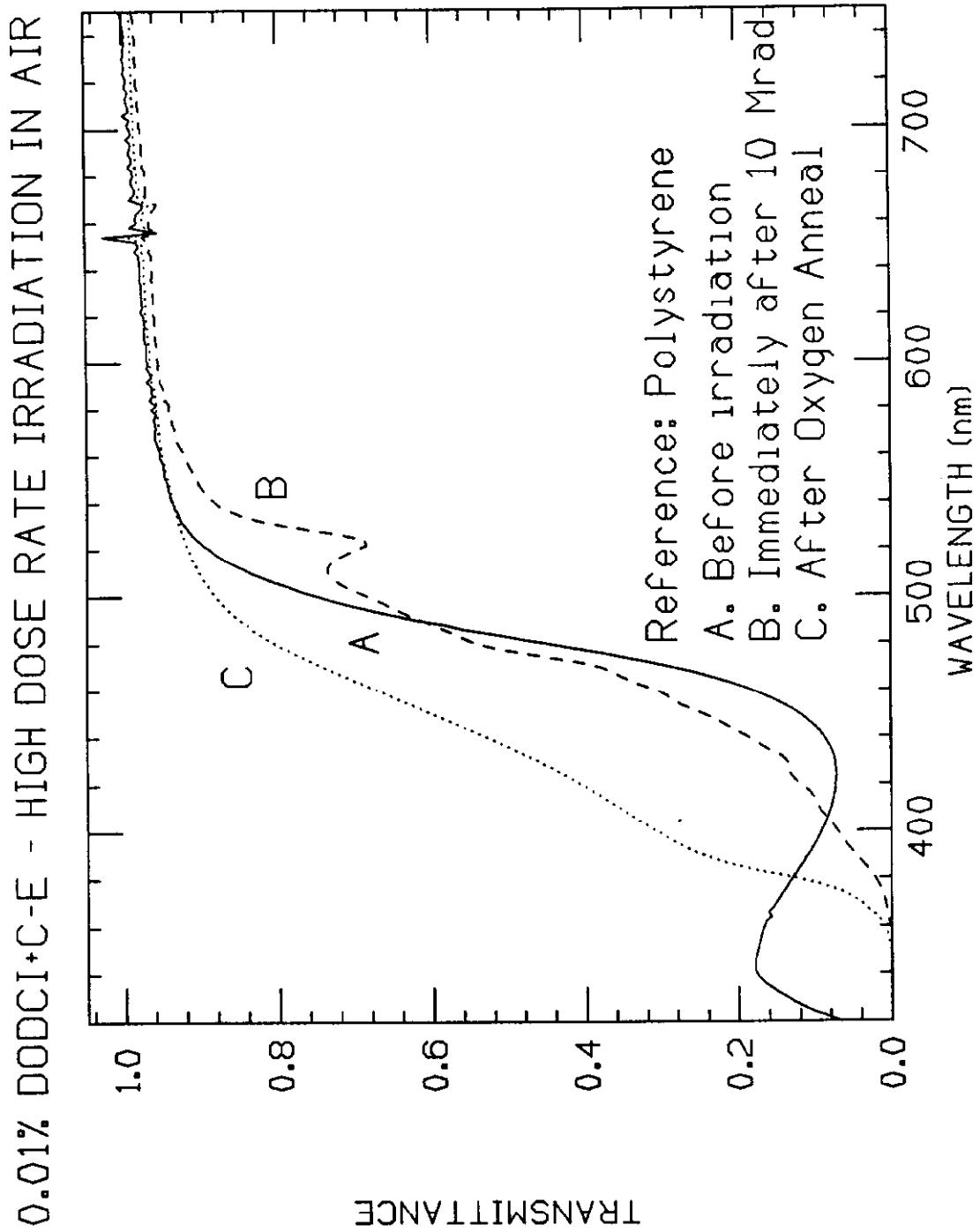


0.02% DOCI - HIGH DOSE RATE IRRADIATION IN AIR

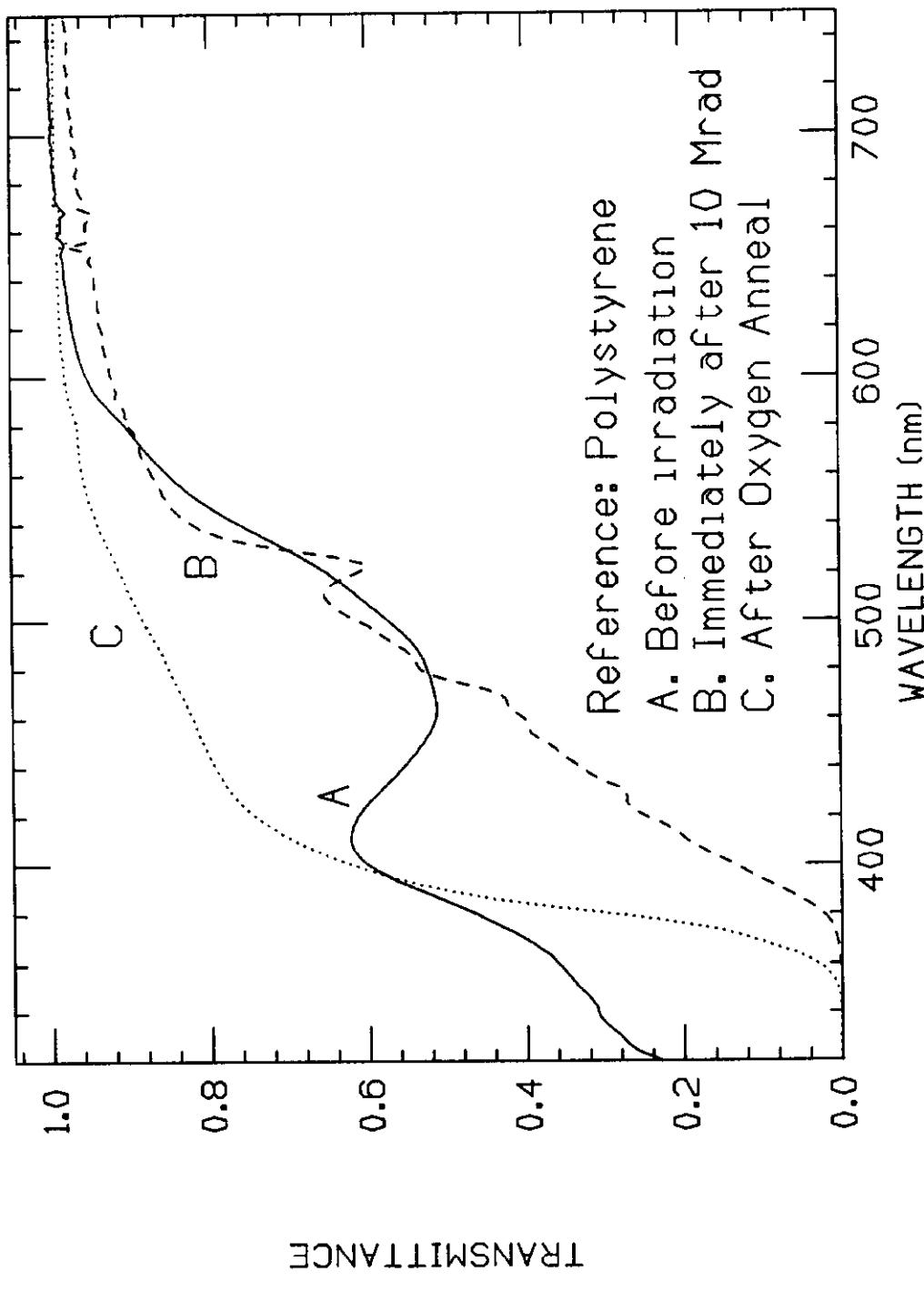


0.02% DODCI - HIGH DOSE RATE IRRADIATION IN AIR

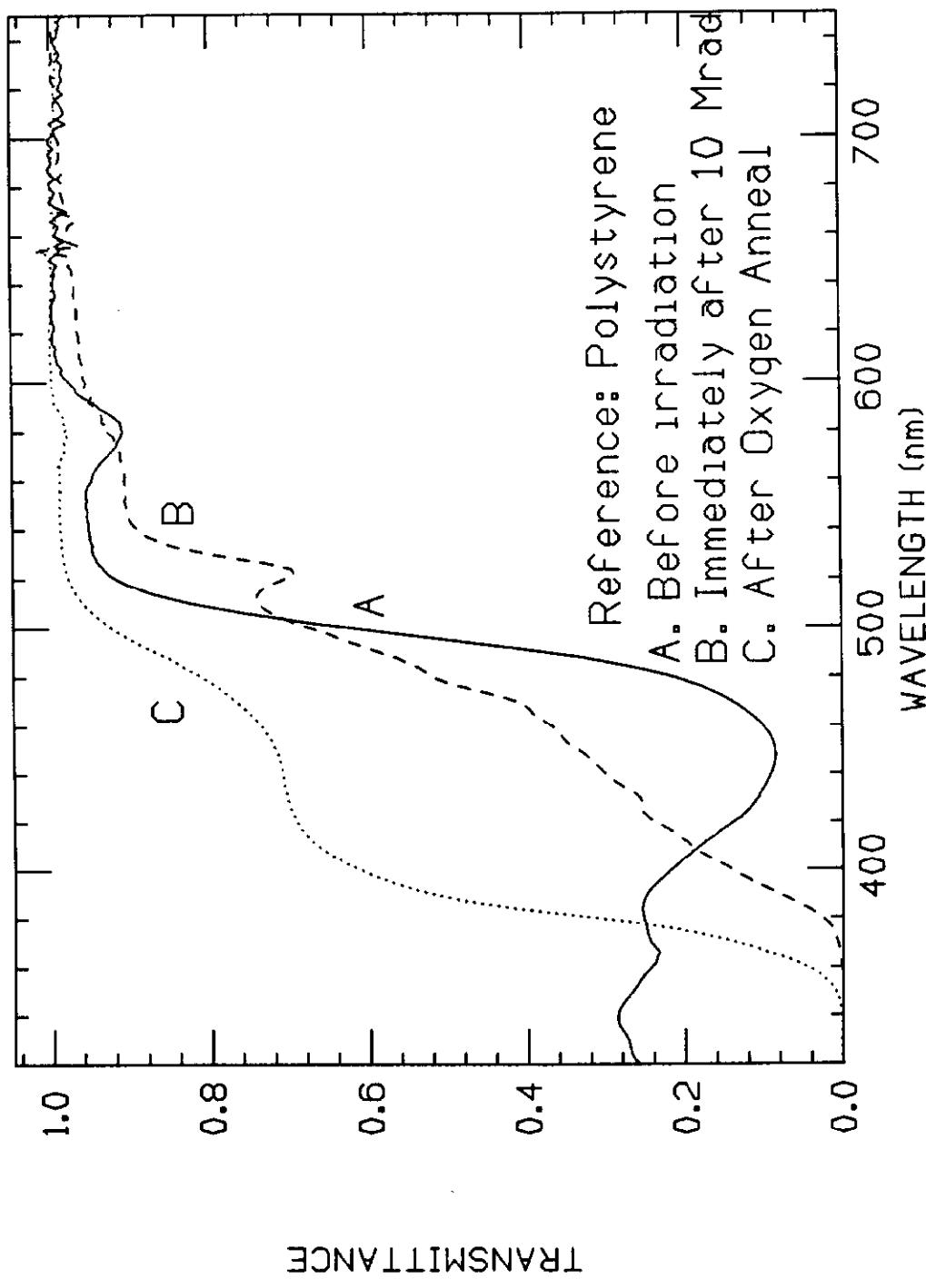




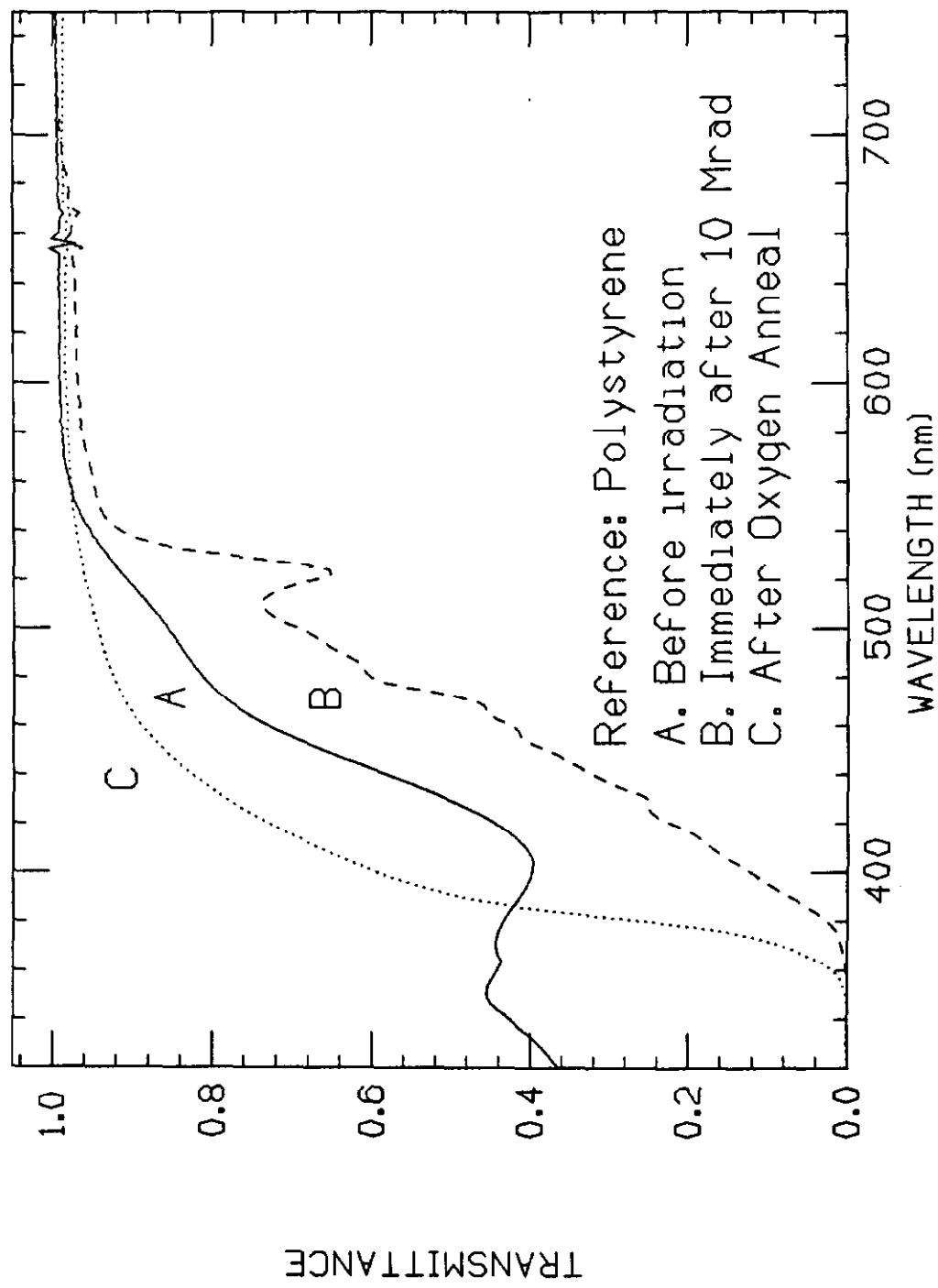
0.02% DQOCl - HIGH DOSE RATE IRRADIATION IN AIR

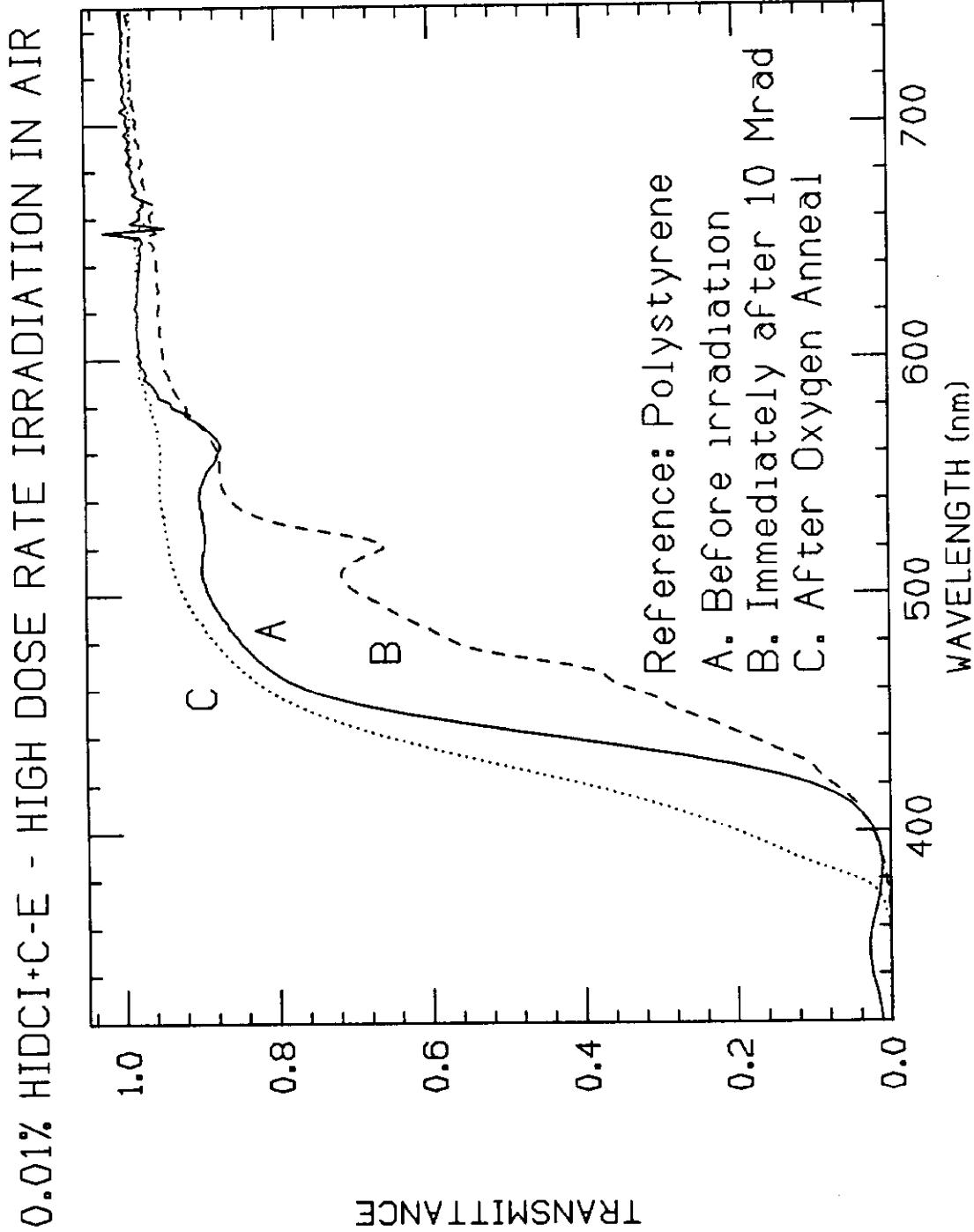


0.02% DTCI - HIGH DOSE RATE IRRADIATION IN AIR

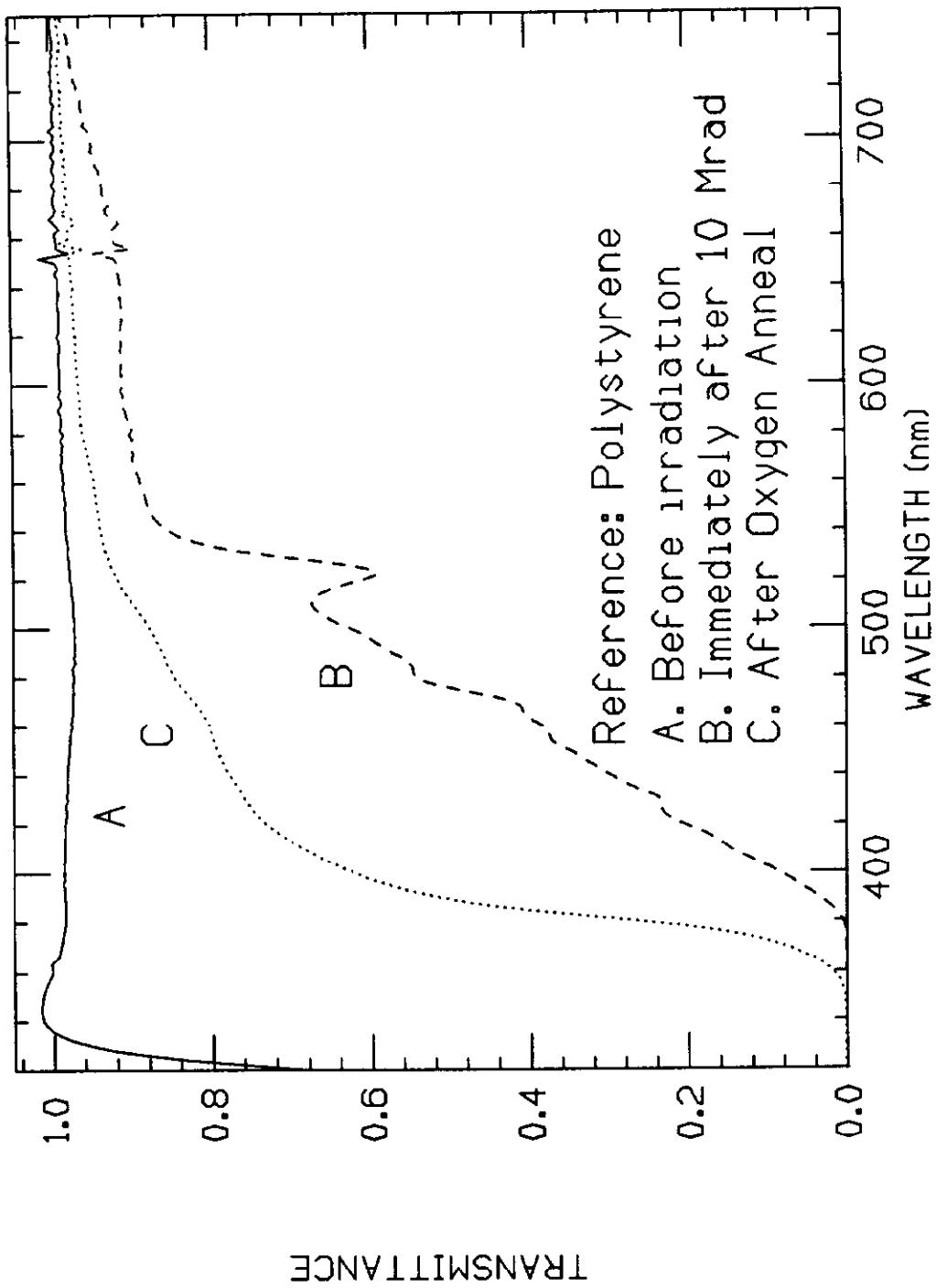


0.01% DTDCI - HIGH DOSE RATE IRRADIATION IN AIR

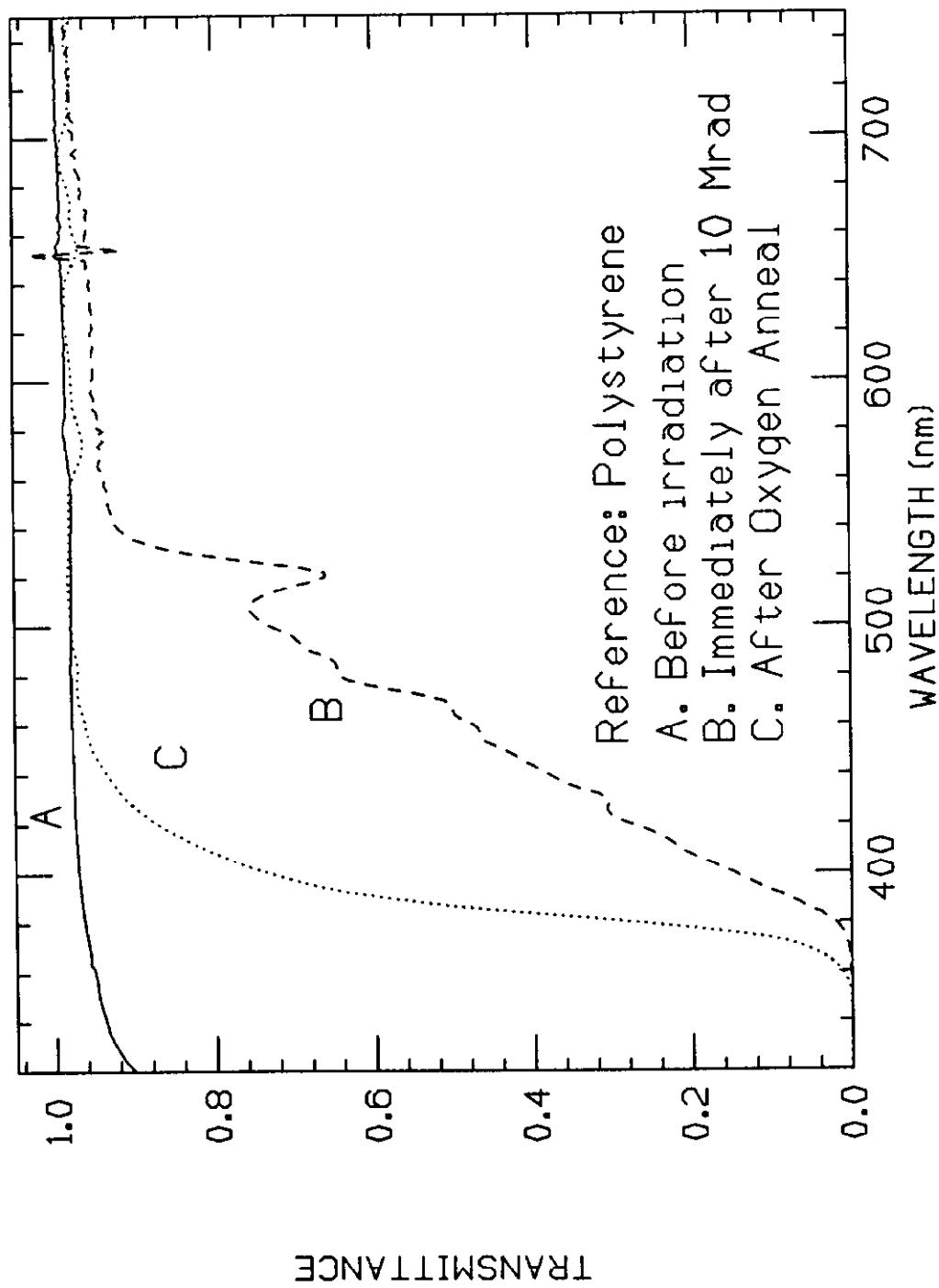




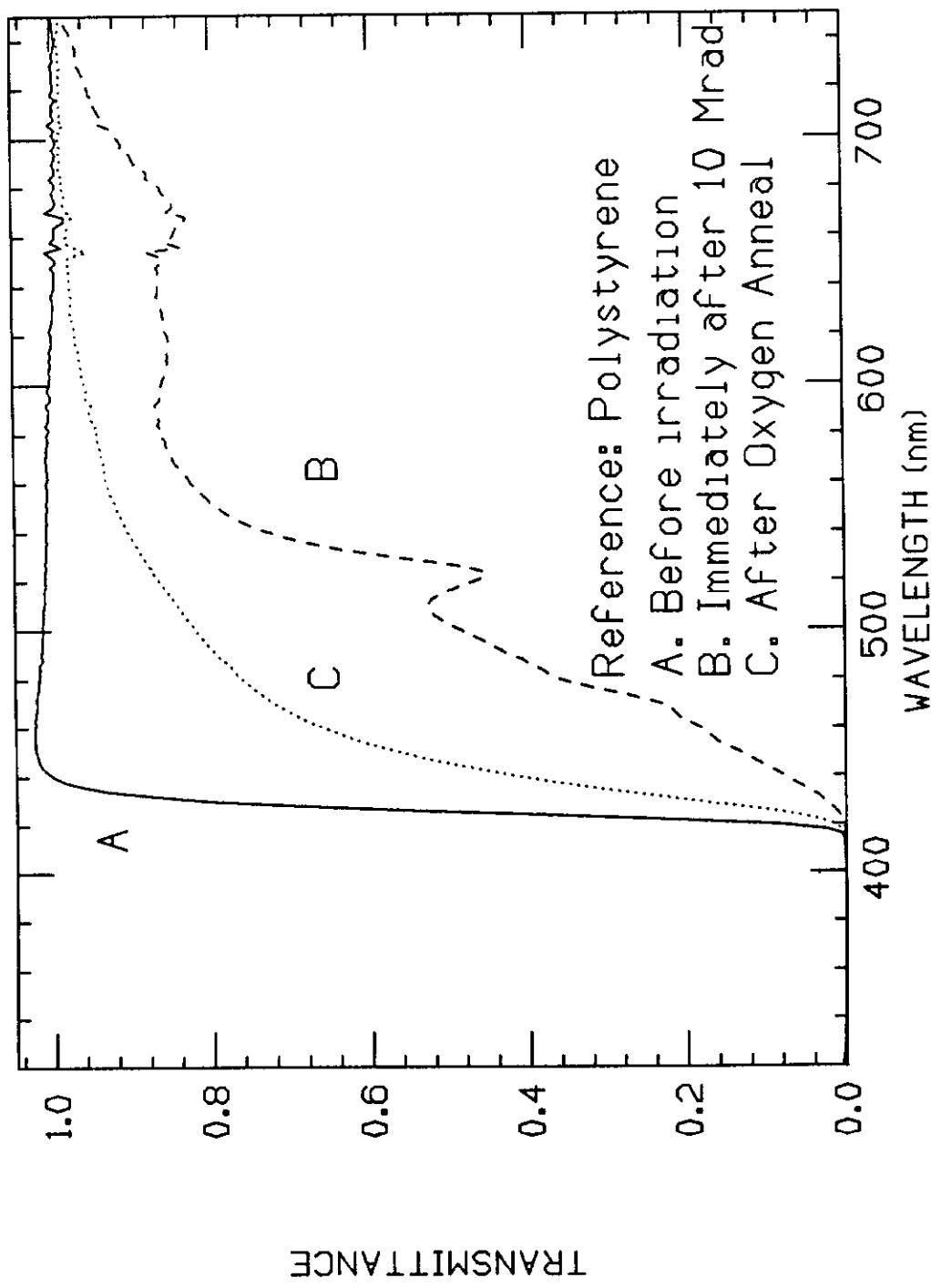
0.02% ISCNFN - HIGH DOSE RATE IRRADIATION IN AIR



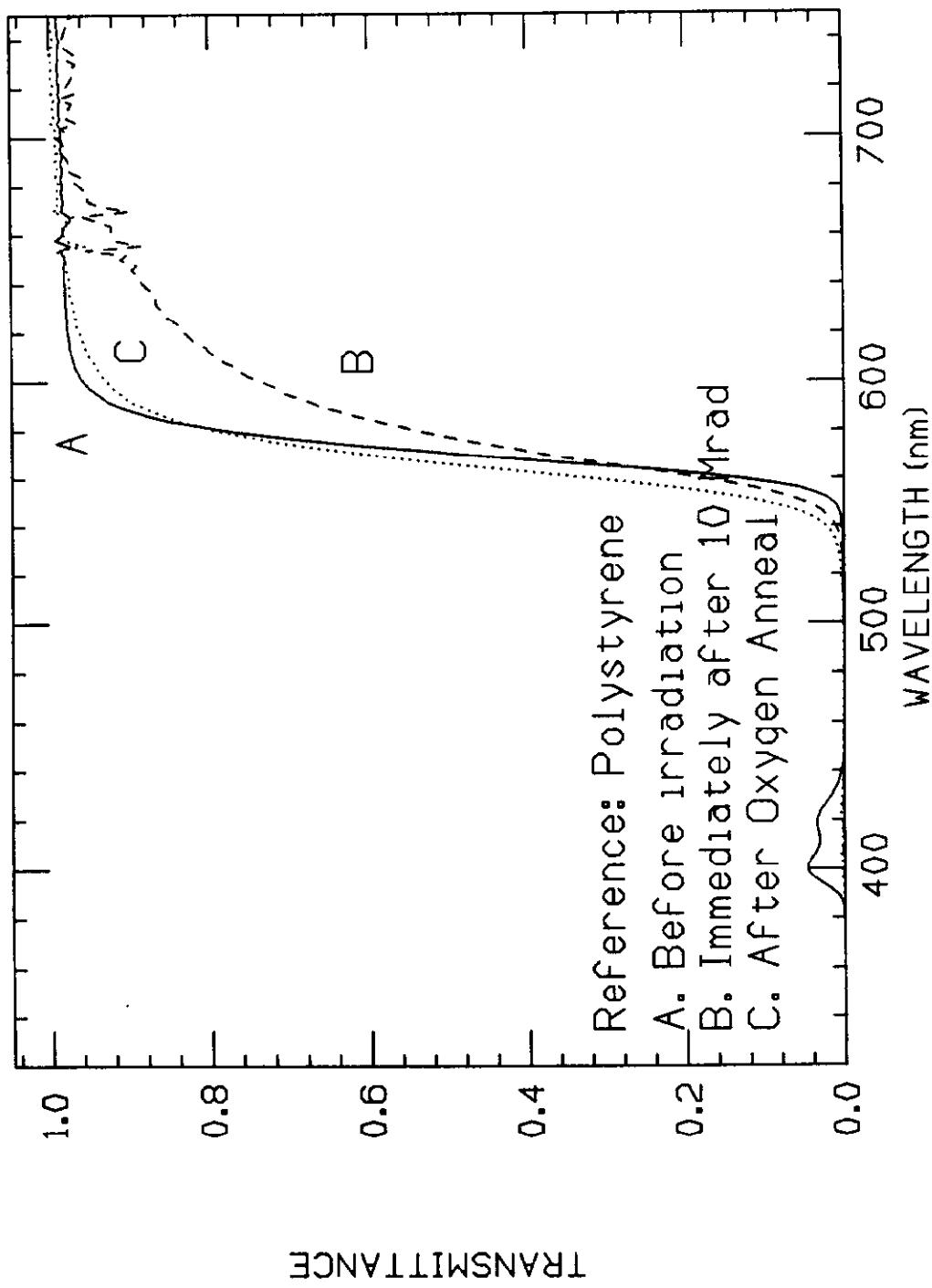
0.02% KITON RED - HIGH DOSE RATE IRRADIATION IN AIR

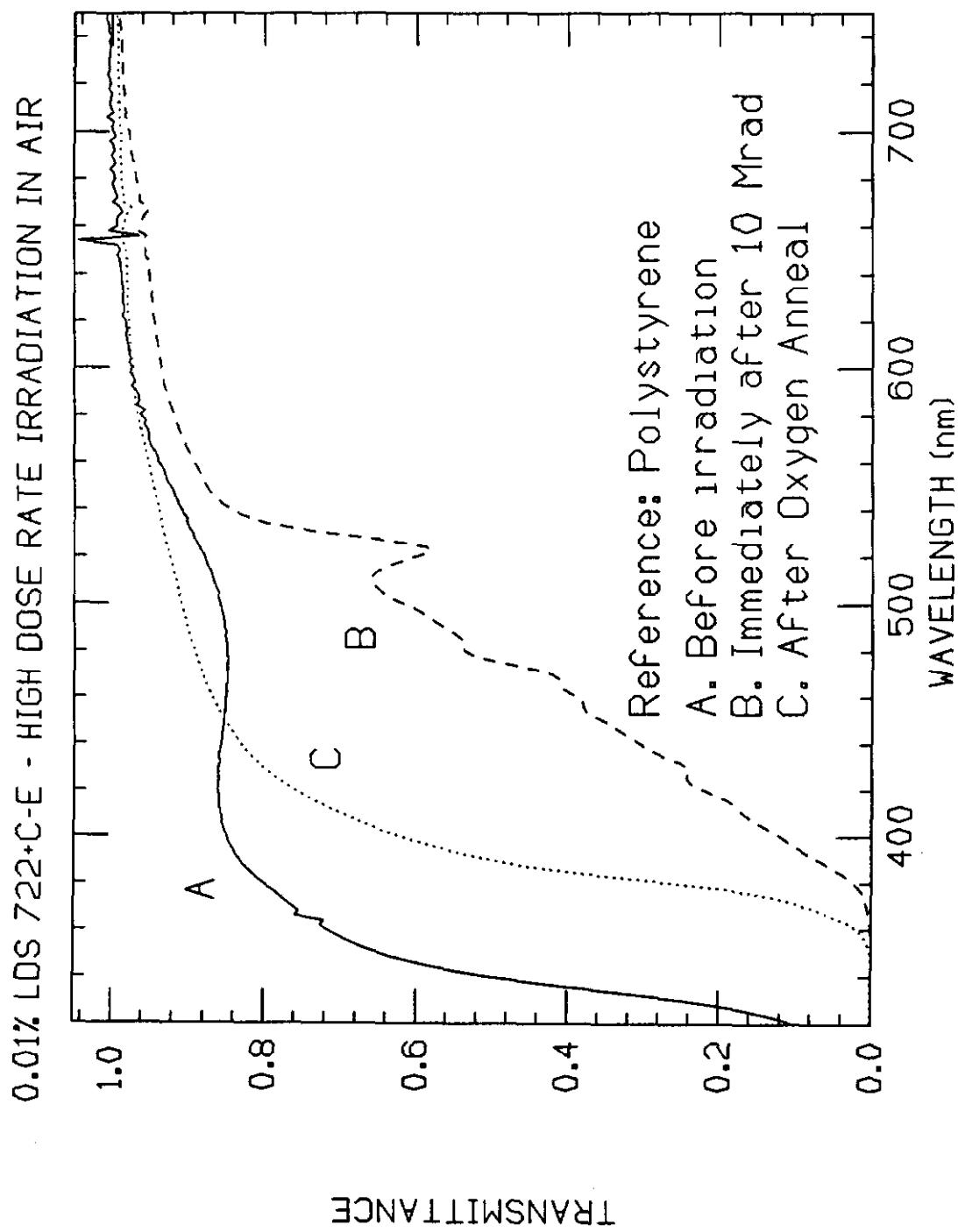


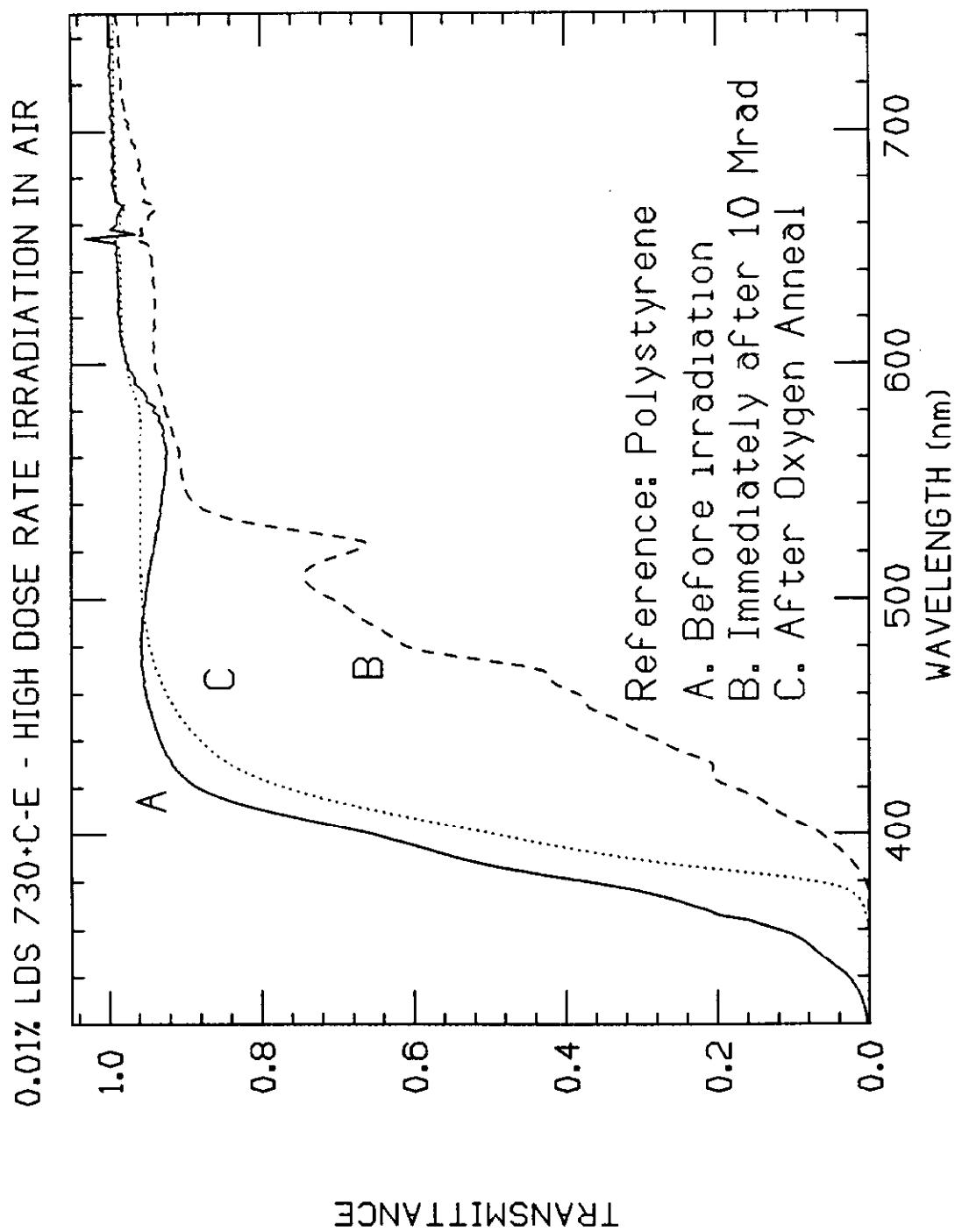
0.02% LD 490 - HIGH DOSE RATE IRRADIATION IN AIR



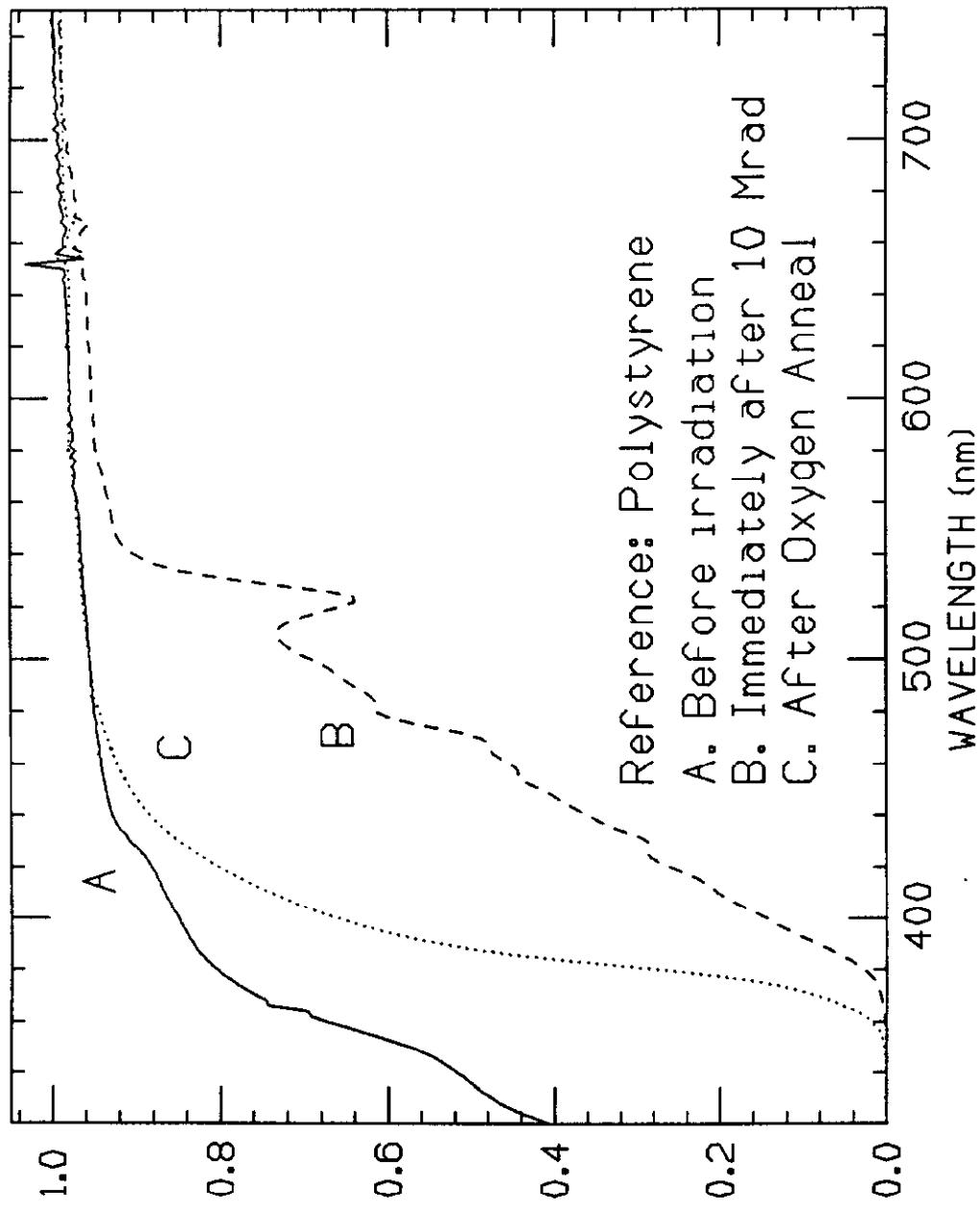
0.02% LD 688 - HIGH DOSE RATE IRRADIATION IN AIR

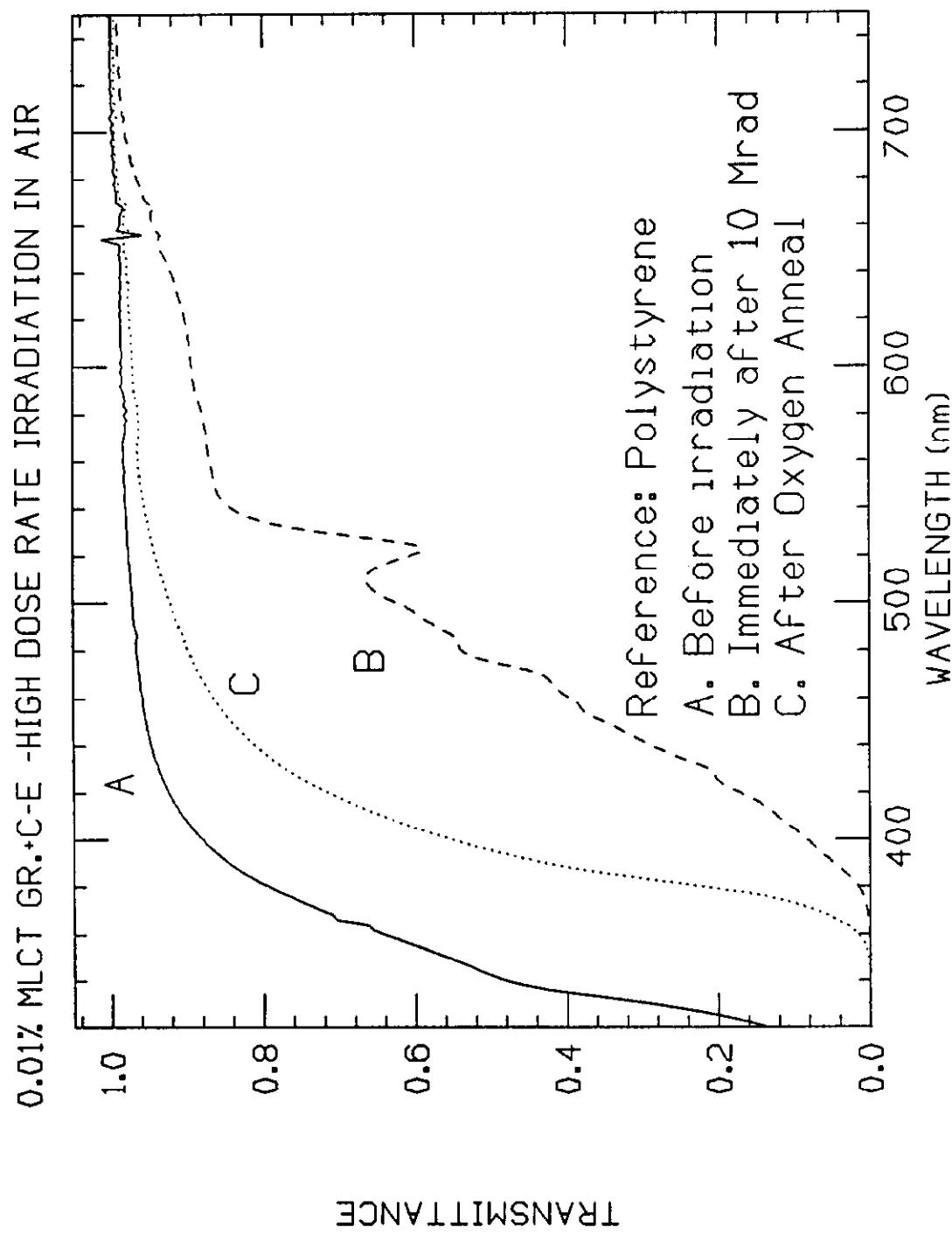


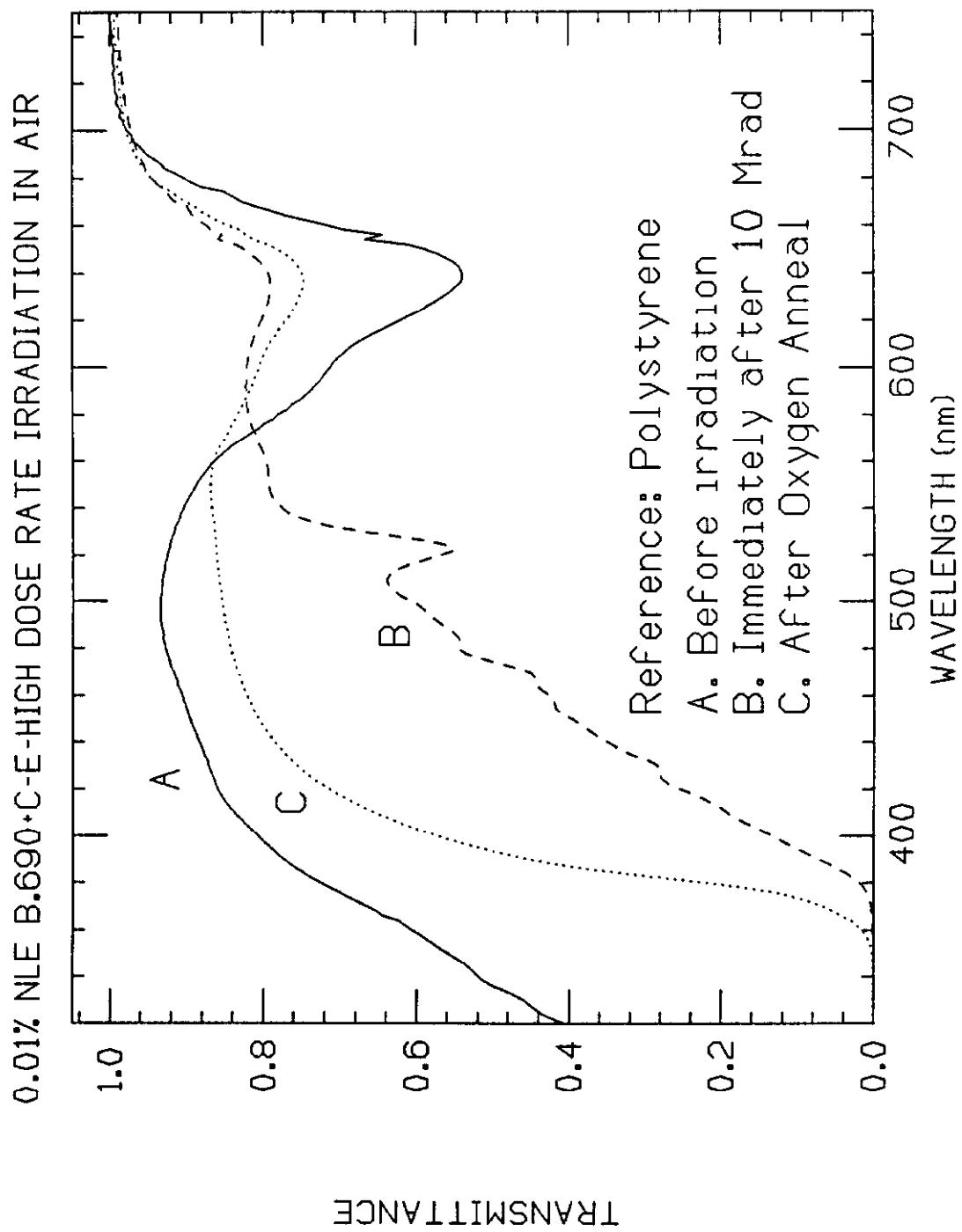




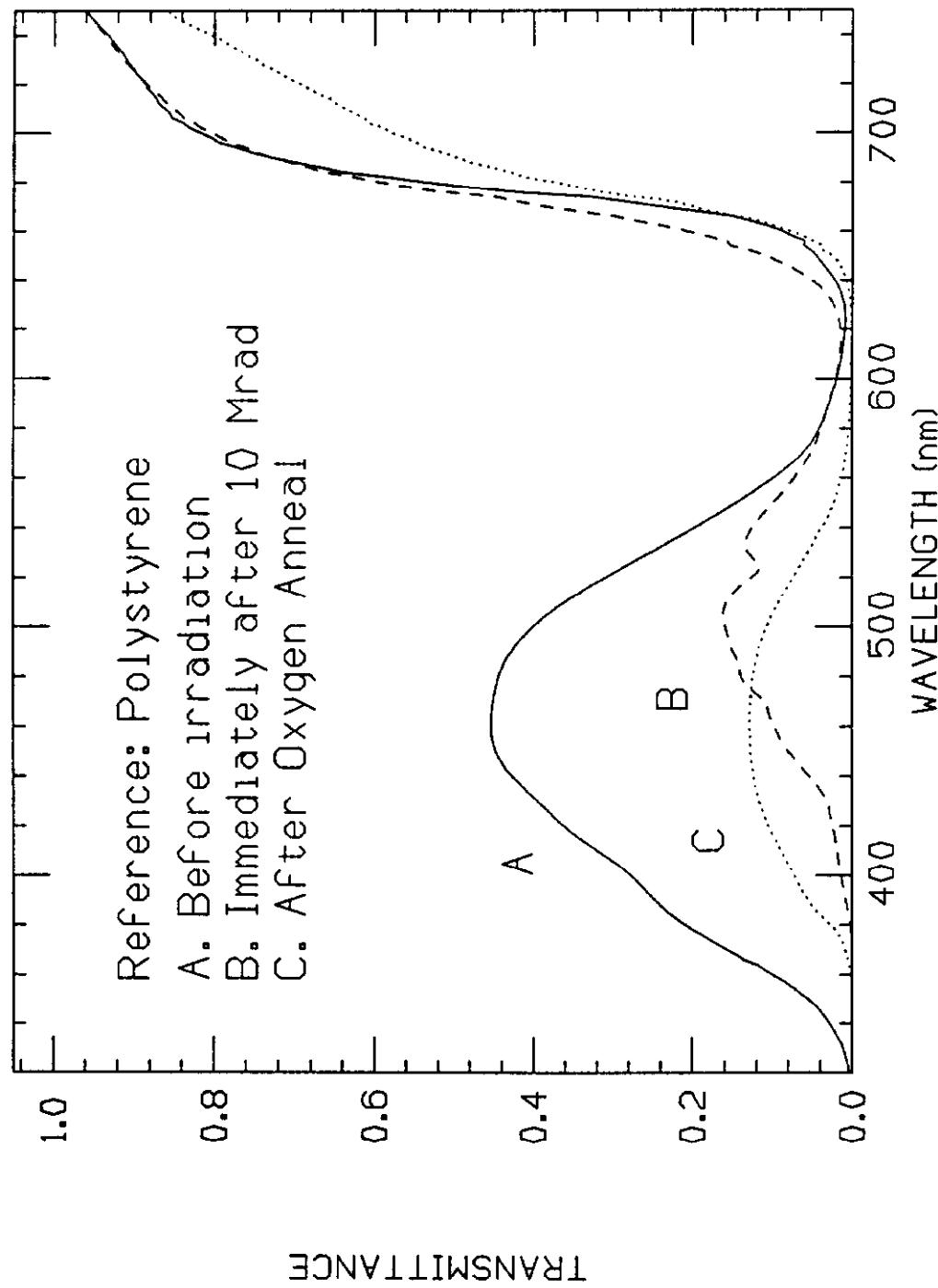
0.01% LDS 750+C-E - HIGH DOSE RATE IRRADIATION IN AIR

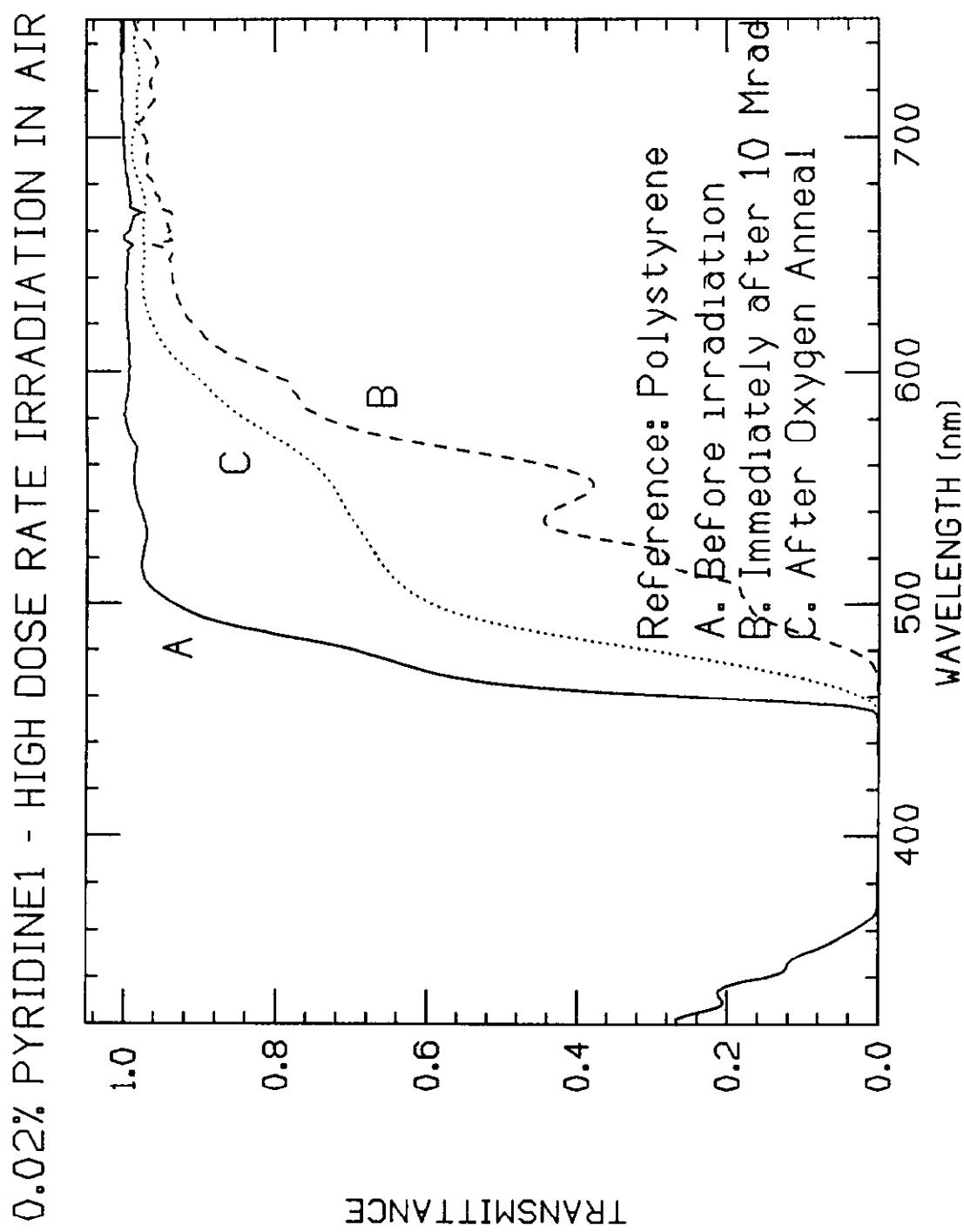


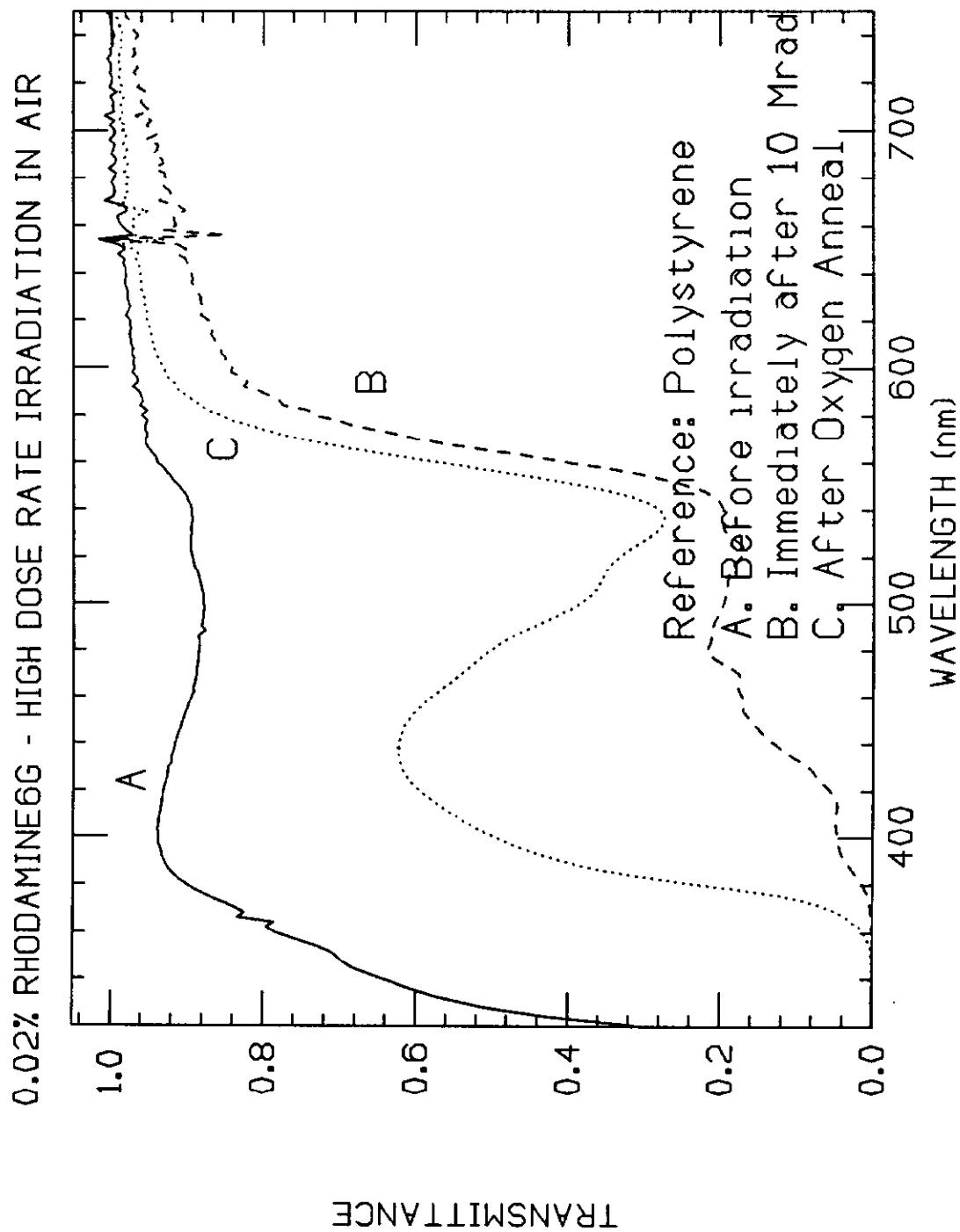




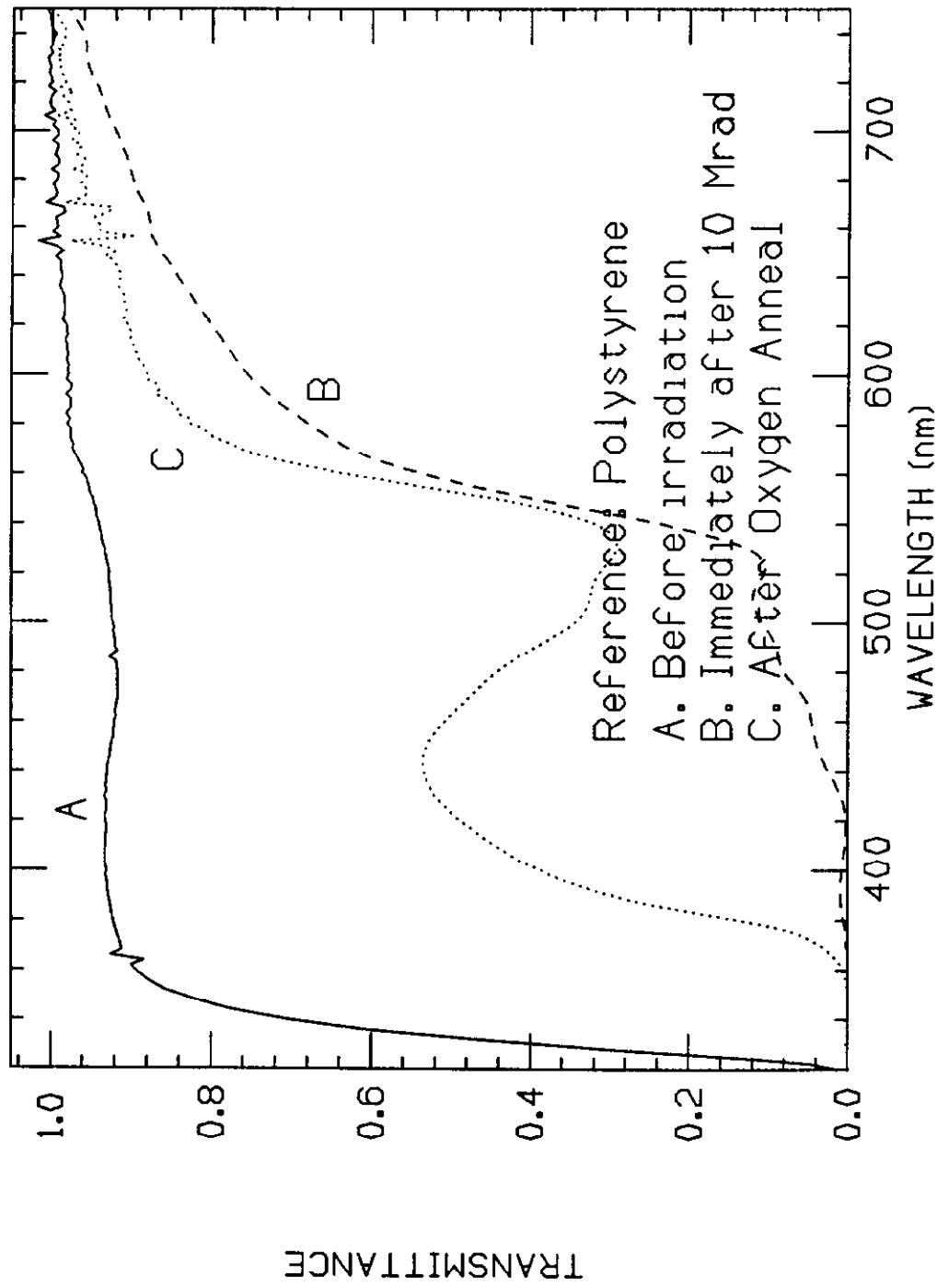
0.01% OXAZINE 725 - HIGH DOSE RATE IRRADIATION IN AIR

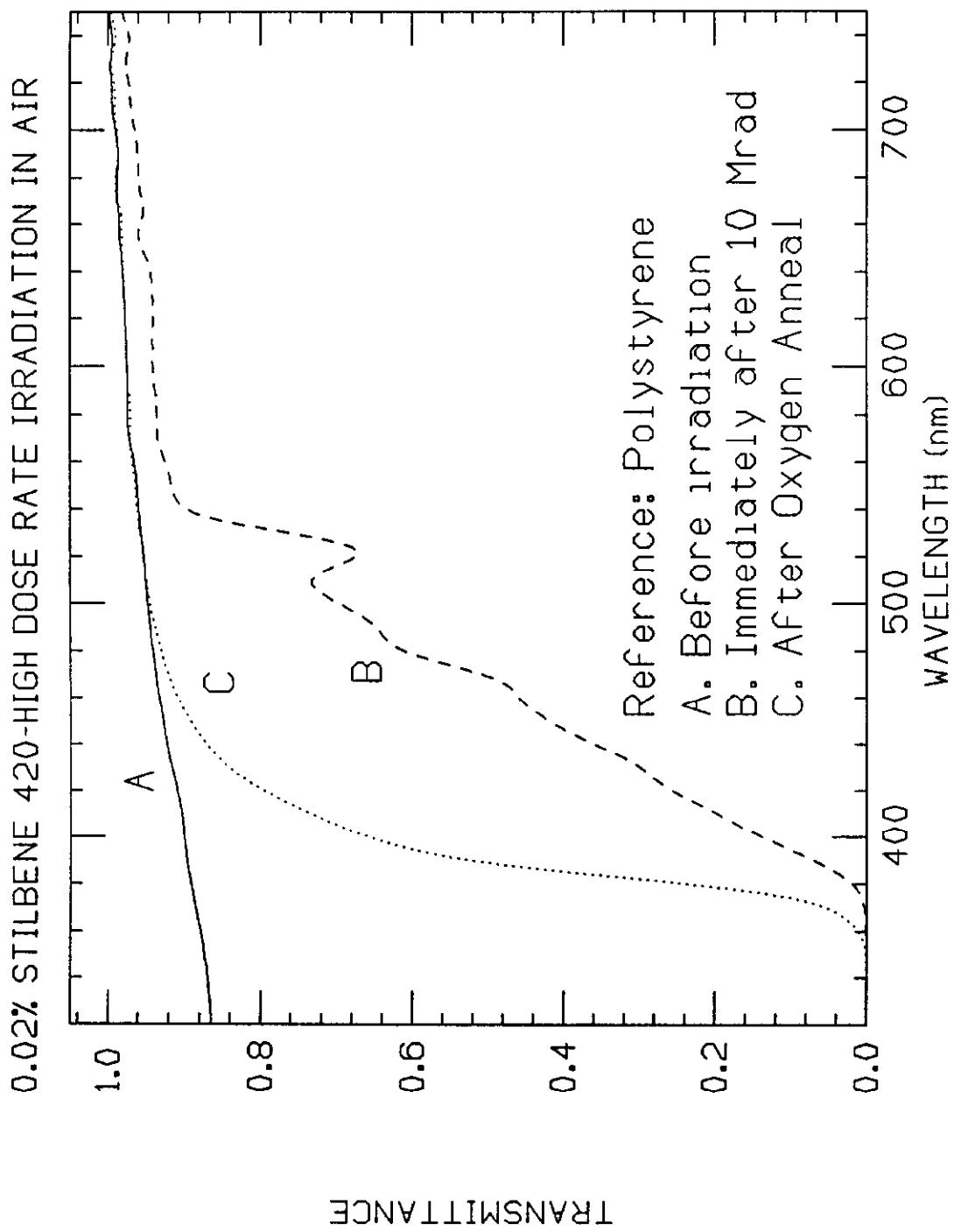




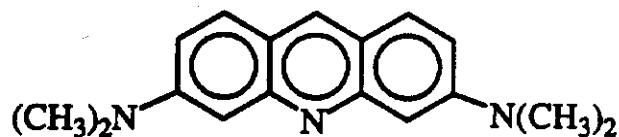


0.02% RHODAMINE575 -HIGH DOSE RATE IRRADIATION IN AIR

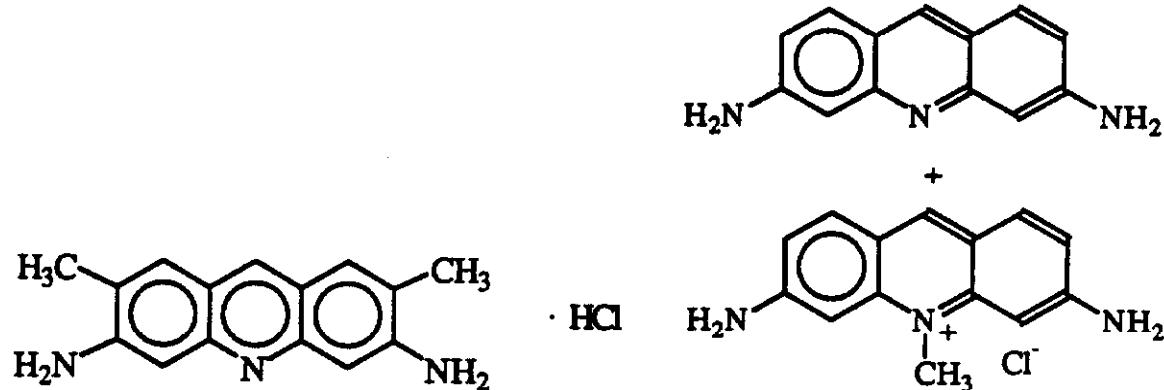




APPENDIX A: LIST OF DOPANT STRUCTURES

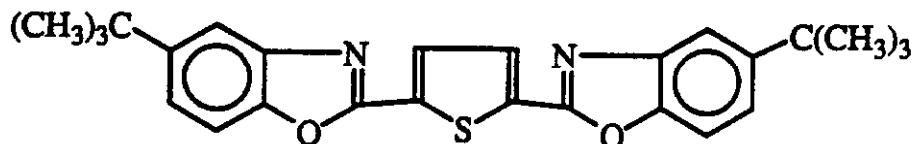


ACRIDINE O B

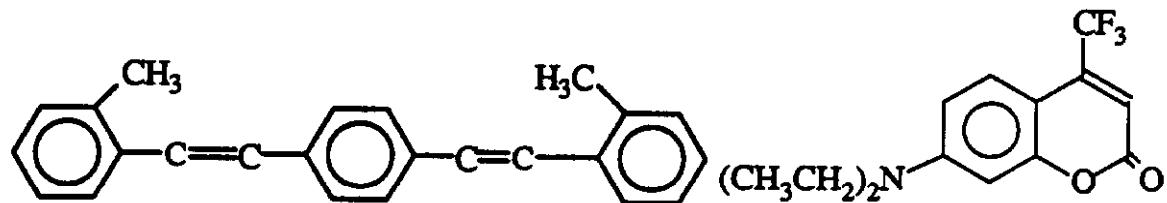


ACRIDINE Y

ACRIFLAVINE

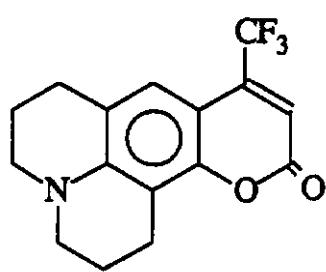


BBOT

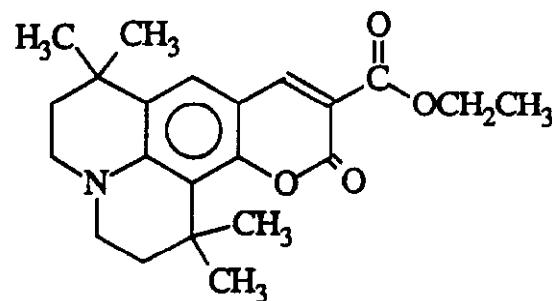


bis-MSB

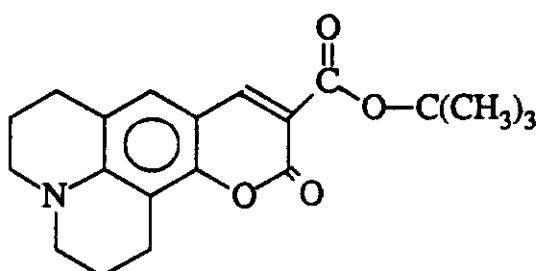
C35/C481



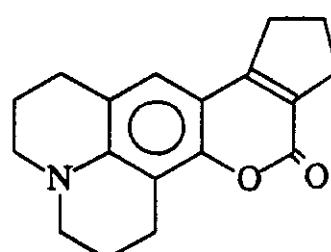
C153K/C153LP



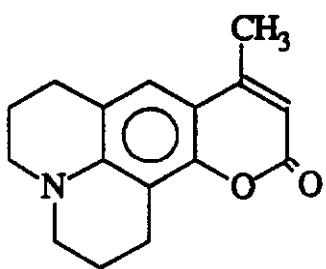
C314T



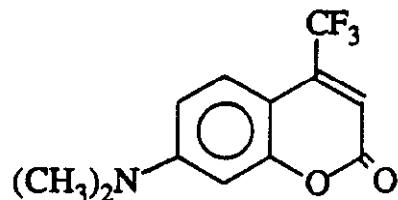
C338



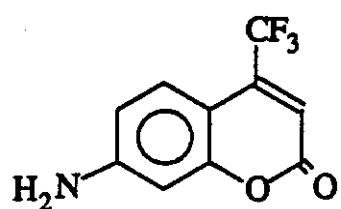
C478



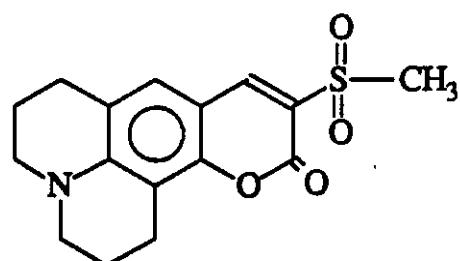
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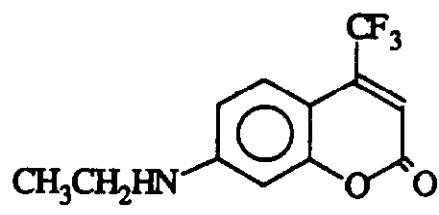
C485



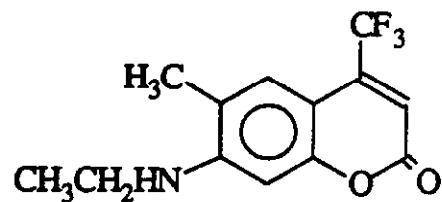
C490



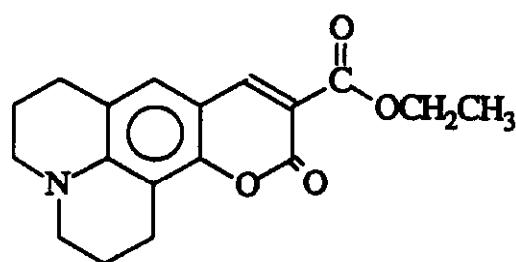
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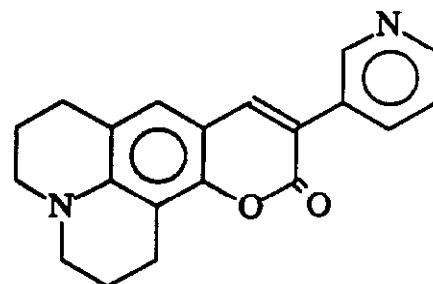
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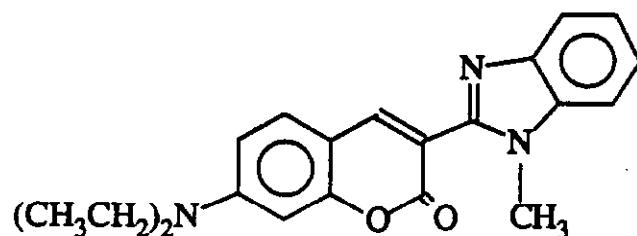
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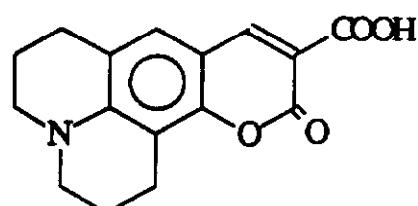
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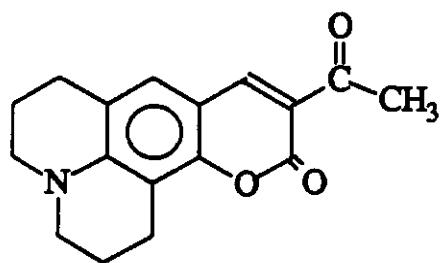
C510



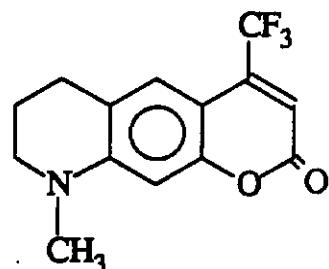
C515



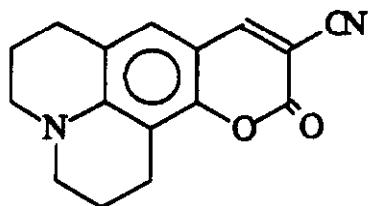
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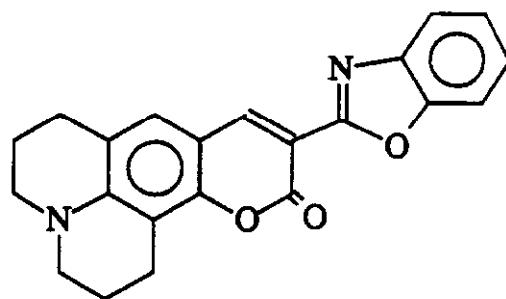
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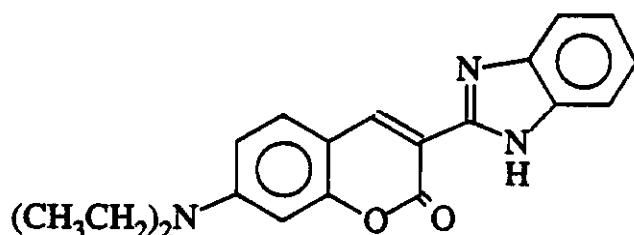
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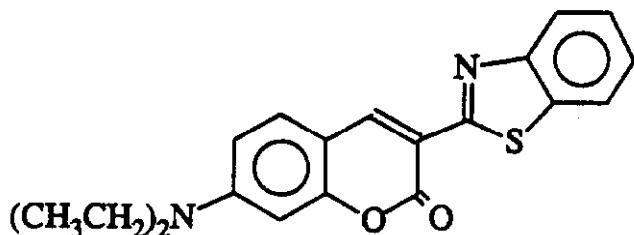
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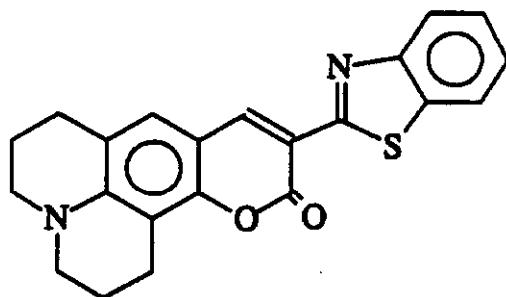
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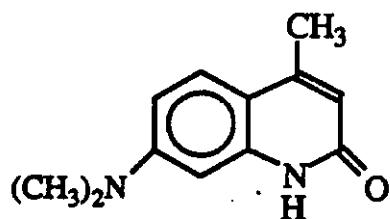
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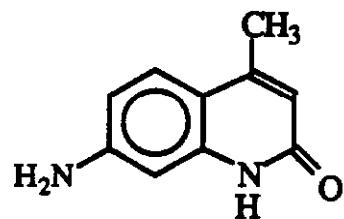
C540



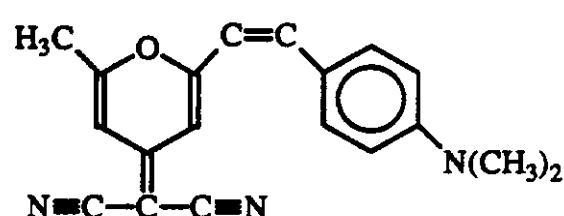
C545



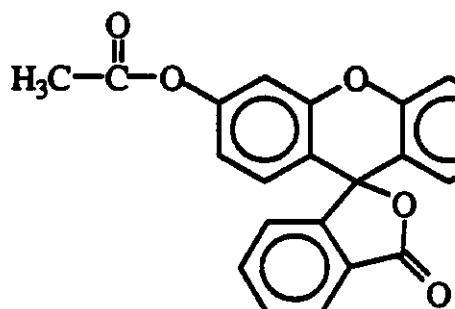
CARBOSTYRIL3



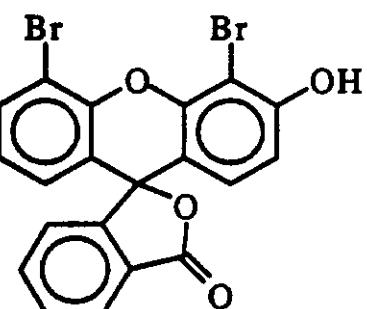
CBSTY124



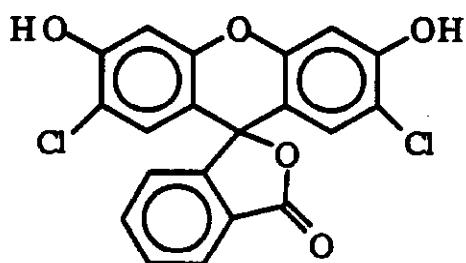
DCM/DCM2



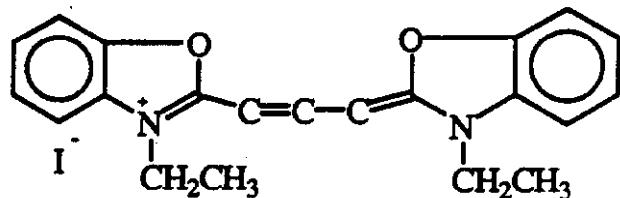
DiACFN



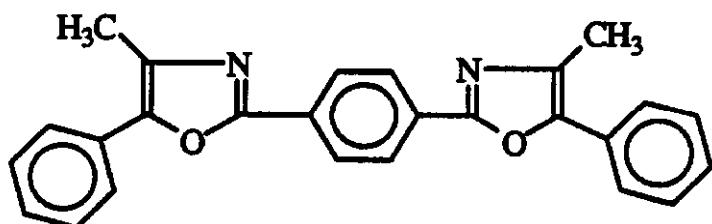
DiBFRN



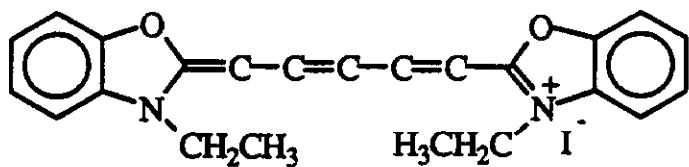
DiCLFN



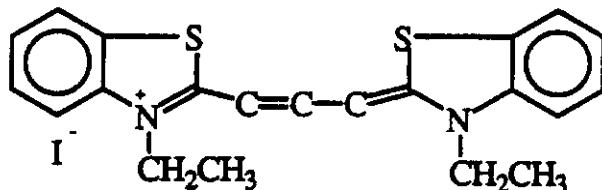
DOCI



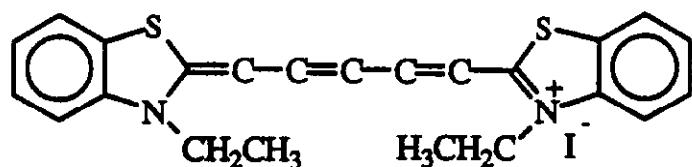
DMPOPOP



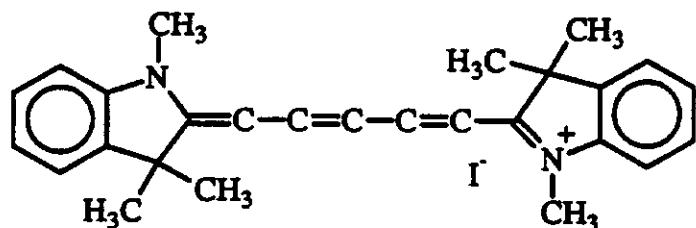
DODCI



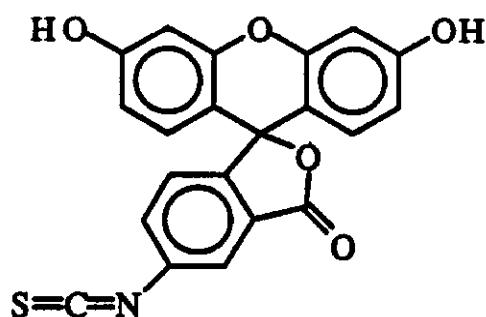
DTCl



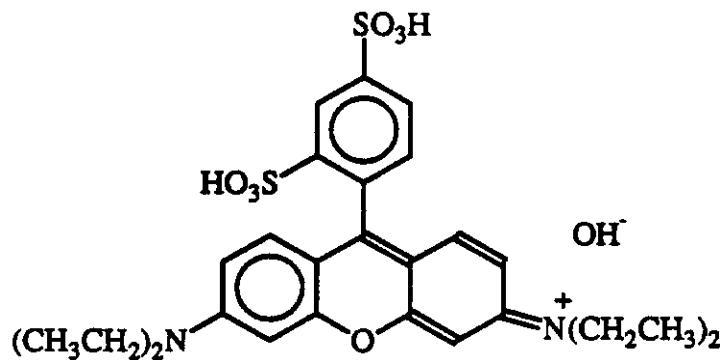
DTDCl



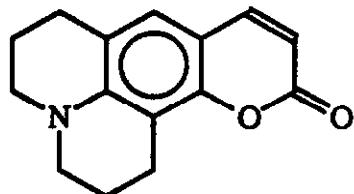
HIDCl



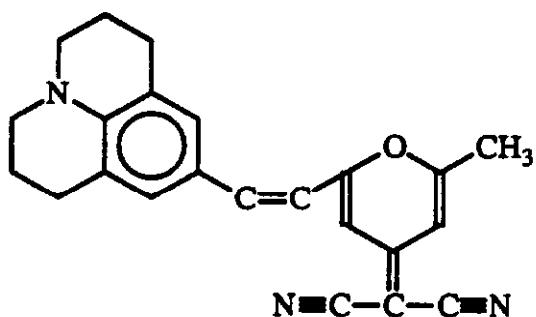
ISCNFn



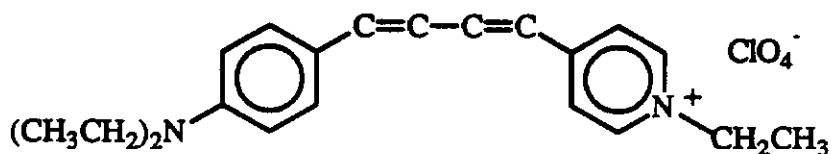
KITON RED



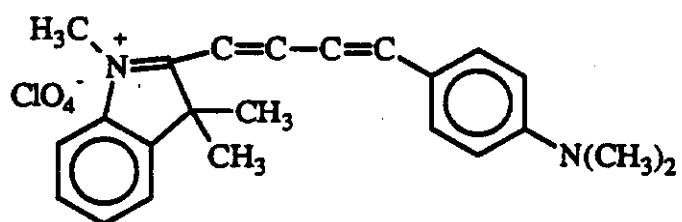
LD490



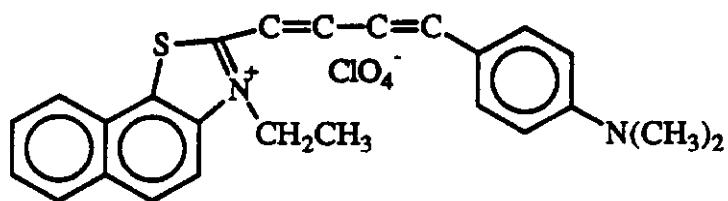
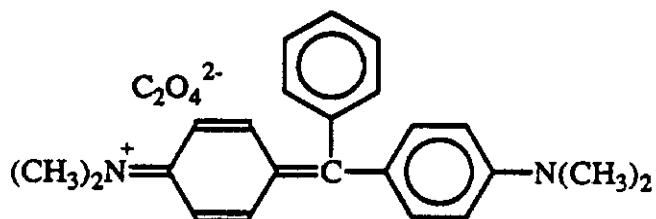
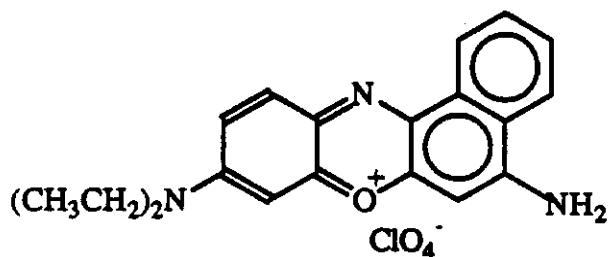
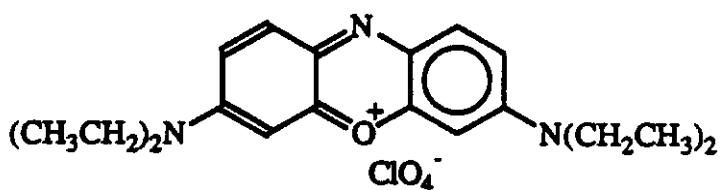
LD688

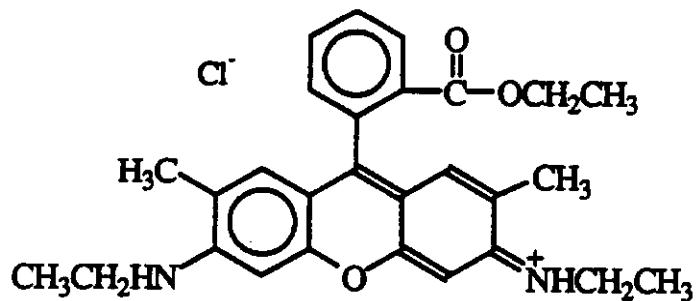
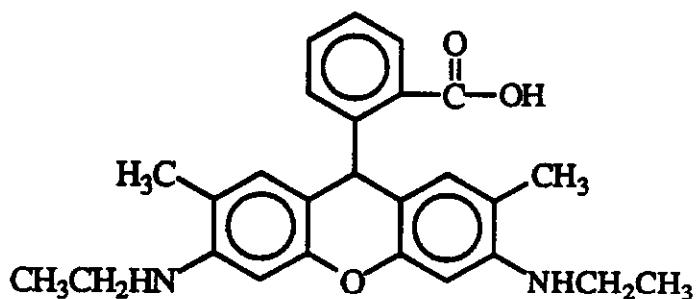
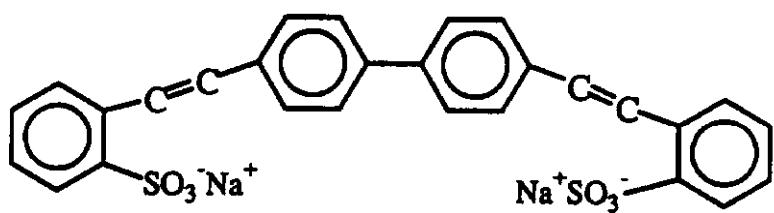


LDS722



LDS730

**LDS750****MALACHITE GREEN****NILE BLUE****OXAZINE 725**

**RHODAM 6G****RHOD 575****STILBENE 420**

APPENDIX B: LIST OF DOPANT NAMES

DOPANTS	CAS #	NAME
ACRIDINE O B ACRIDINE Y ACRIFLAVINE	494-38-2 135-49-9 8048-52-0	3,6-bis(dimethylamino)acridine 3,6-diamino-2,7-dimethylacridine hydrochloride acriflavinium chloride
BBOT bis-MSB	7128-64-5 13280-61-0	2,5-bis(5'-tertbutylbenzoazolyl-(2')thiophene 1,4-bis(2-methylstyryl)benzene
C35/C481 C153K/C153LP C314T	41934-47-8 53518-18-6 113869-06-0	7-(diethylamino)-4-(trifluoromethyl)-2H-1-benzopyran-2-one 2,3,6,7-tetrahydro-9-(trifluoromethyl)-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one 2,3,6,7-tetrahydro-1,1,7,7-tetramethyl-11-oxo-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-10-carboxylic acid ethyl ester
C338	62669-75-4	1,1-dimethyltetethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-10-carboxylate
C478	41175-45-5	2,3,6,7,10,11-hexahydro-1H,5H-cyclopenta[3,4]f[1]benzopyran[6,7,8-ij]quinolizine-12(9H)-one
C480	41267-76-9	2,3,6,7-tetrahydro-9-methyl-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one
C485	53518-14-2	7-(dimethylamino)-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C490	53518-15-3	7-amino-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C498	87331-48-4	2,3,6,7-tetrahydro-10-(methylsulfonyl)-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one
C500	52840-38-7	7-(ethylamino)-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C503	55804-70-1	7-(ethylamino)-6-methyl-4-(trifluoromethyl)-2H-1-benzopyran-2-one
C504	55804-66-5	ethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-10-carboxylate
C510	87349-92-6	2,3,6,7-tetrahydro-10-(3-pyridinyl)-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one
C515	41044-12-6	7-(dimethylamino)-3-(1-methyl-1H-benzimidazole-2-yl)-2H-1-benzopyran-2-one
C519	55804-65-4	2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-10-carboxylic acid
C521	55804-67-6	10-acetyl-2,3,6,7-tetrahydro-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one
C522	53518-19-7	6,7,8,9-tetrahydro-9-methyl-4-(trifluoromethyl)-2H-pyran[3,2-g]quinolin-2-one
C523	55804-68-7	2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-10-carbonitrile
C525	87331-47-3	10-(2-benzoazolyl)-2,3,6,7-tetrahydro-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one
C535	27425-55-4	3-(1H-benzimidazole-2-yl)-7-(diethylamino)-2H-[1]benzopyran-2-one
C540	38215-36-0	3-(2-benzothiazolyl)-7-(diethylamino)-2H-[1]benzopyran-2-one
C545	85642-11-1	10-(2-benzothiazolyl)-2,3,6,7-tetrahydro-1H,5H,11H-[1]benzopyran[6,7,8-ij]quinolizine-11-one
CBSTY 3 CBSTY 124	19840-99-4	7-amino-4-methyl-2(1H)-quinolinone
DCM/DCM2 DIACFN DiBRFN	51325-91-8 596-09-8 596-03-2	{2-[2-[4-(dimethylamino)phenyl]ethenyl]-6-methyl-4H-pyran-4-ylidene}-propanedinitrile fluorescein diacetate 4',5'-dibromofluorescein

DOPANTS	CAS #	NAME
DICLFNFNS48 DMPOPOP DOCl DODCl DQOCl DTCl DTDCl	76-54-0 3073-87-8 14806-50-9 • 514-73-88	2',7'-dichloro-3',6'-dihydroxy-spiro[isobenzofuran-1(3H),9'-[9H]xanthene-3-one 1,4-bis(4-methyl-5-phenyloxazol-2-yl)-benzene diethyloxacarbocyanine Iodide 3-ethyl-2-[5-(3-ethyl-2(3H)-benzoxazolylidene)-1,3-pentadienyl]-benzoxazolium Iodide diethyliothiacarbocyanine Iodide 3-ethyl-2-[5-(3-ethyl-2(3H)-benzthiazolylidene)-1,3-pentadienyl]-benzthiazolium Iodide
HIDC IODIDE	36536-22-8	2-[5-(1,3-dihydro-1,3,3-trimethyl-2H-indol-2-ylidene)-1,3-pentadienyl]-1,3,3-trimethyl-3H-indolium Iodide
ISCNFN	3326-32-7	fluorescein Isothiocyanate Isomer I
KITON RED 620	2609-98-3	N-[6-(diethylamino)-9-(2,4-disulfophenyl)-3H-xanthan-3-ylidene]-N-ethyl-ethanaminium Hydroxide
LD490 LD688	58336-35-9 51325-95-2	2,3,6,7-tetrahydro-1H,5H,11H,[1]benzopyrano[6,7,8-ij]-quinoliz-11-one 2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzolij)]quinolizin-9-ylidene]-4H-pyran-4-ylidene] propanedinitrile
LDS722 LDS730 LDS750	89846-21-9 76433-27-7 89872-07-1	4-[4-(dimethylamino)phenyl]-1,3-butadienyl]-1-ethyl-pyridinium perchlorate 2-[4-(dimethylamino)phenyl]-1,3-butadienyl]-1,3,3-trimethyl-3H-indolium perchlorate 2-[4-(dimethylamino)phenyl]-1,3-butadienyl]-3-ethylnapthalq2,1-djthiazoliumperchlorate
MALACHITE GREEN	18015-76-4	N-[4-[4-(dimethylamino)phenyl]methylene]-2,5-cyclohexadien-1-ylidene-N-methylnethanaminium ethanedioate(2:2:1)
NILE BLUE	53340-16-2	5-amino-9-(diethylamino)-benzo[a]phenoxazin-7-ium perchlorate
OXAZINE 725	24796-94-9	3,7-bis(diethylamino)-phenoxazin-5-ium perchlorate
PYRIDIN1	•	•
RHODAMINE 6G RHODAMINE575	989-38-8 25152-49-2	9-(2-(ethoxycarbonyl)phenyl)-3,6-bis(ethylamino)-2,7-dimethyloxanthyllium chloride 2-[6-(ethylamino)-3-(ethylamino)-2,7-dimethyl-3H-xanthen-9-yl]-benzoic acid
STILBENE 420	27344-41-8	2,2'-(1,1'-biphenyl)-4,4'-diyldi-2,1-ethenediyi)bis-benzenesulfonic acid disodium salt

* information not available in MSDS